Cardboard Automata

Cardboard Automata are a playful way to explore simple machine elements such as cams, levers, and linkages, while creating a mechanical sculpture.

The Cardboard Automata activity was inspired by
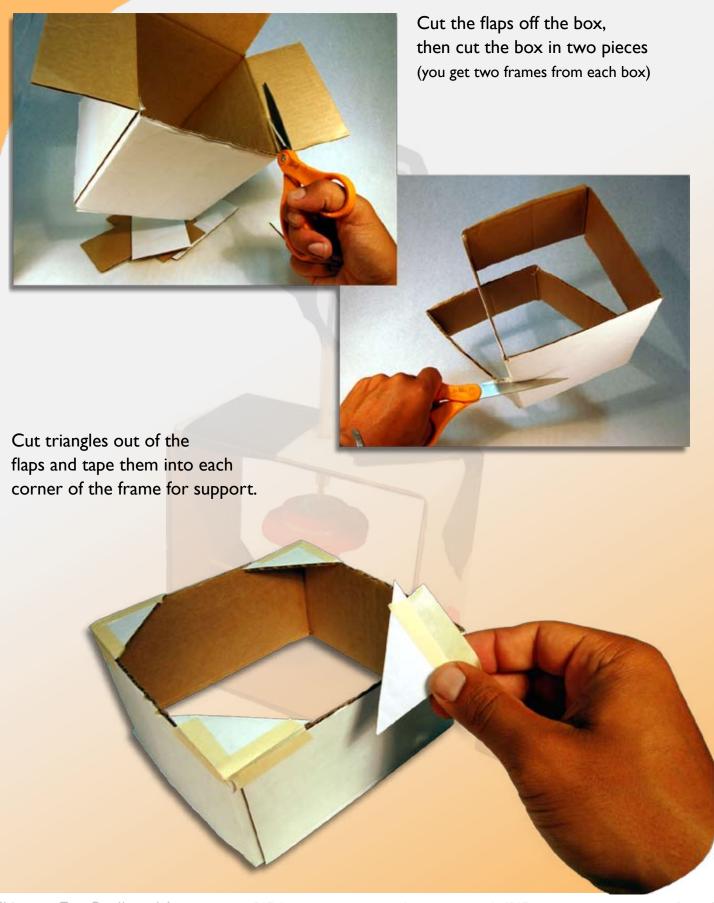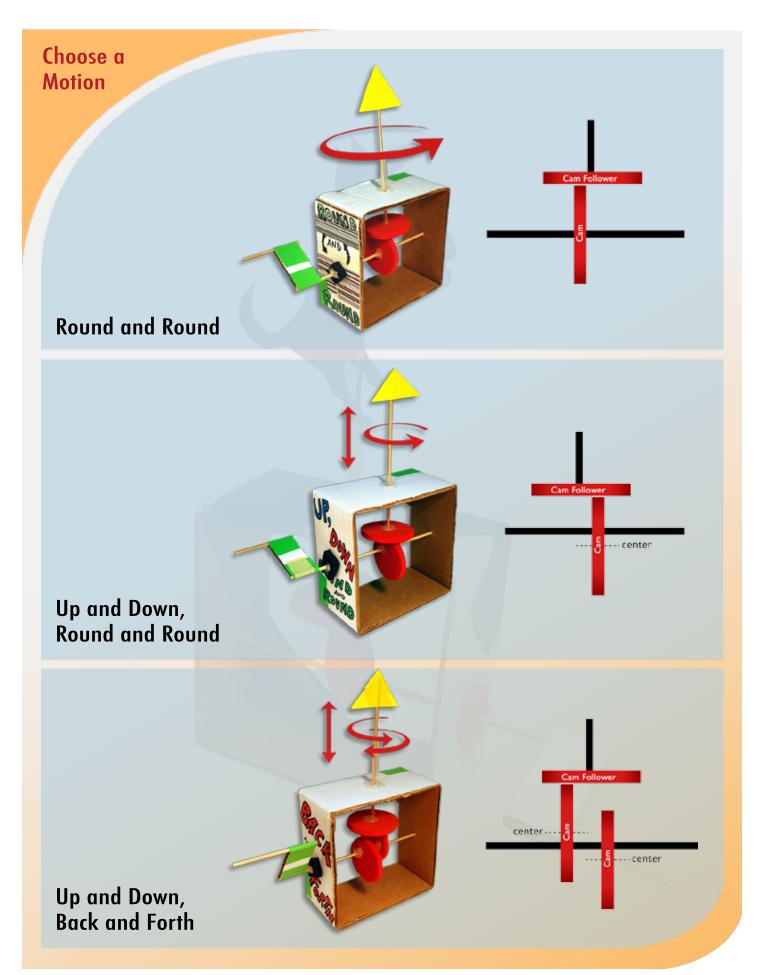

Cabaret Mechanical Theatre

Working with simple materials, this activity is easy to get started, and may become as complex as your mechanical sculpture ideas.

TRY IT! Collect these things:
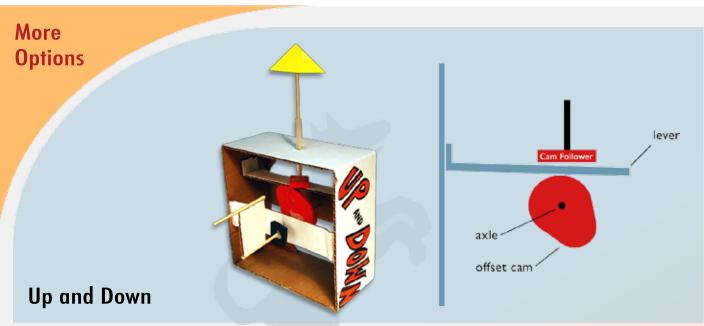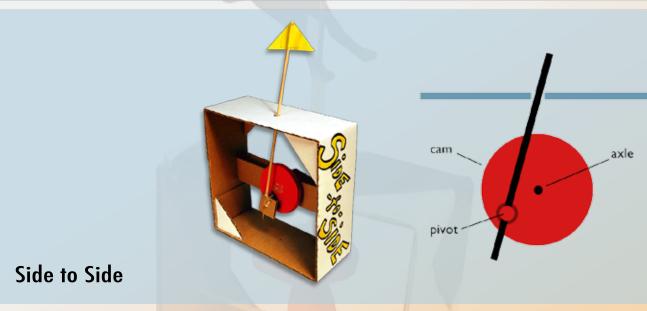
Cardboard box 15x15cm (6"x6")
scissors, masking tape,

nail or screw, drinking straw, hot melt glue,
glue gun, skewer stick, thick (6mm) Foamies* nut or washer (optional),
materials for decoration, thin (2mm) Foamies* markers/pens, feathers,
pipe cleaners *(craftsuppliesforless.com)

PIE Institute shares a playful and inventive approach to teaching science, art, and technology.

MAKE A FRAME

Cut the flaps off the box,
then cut the box in two pieces
(you get two frames from each box)

Cut triangles out of the
flaps and tape them into each
corner of the frame for support.

Round and Round

Up and Down, Round and Round

Up and Down, Back and Forth

Up and Down

lever

Cam Follower
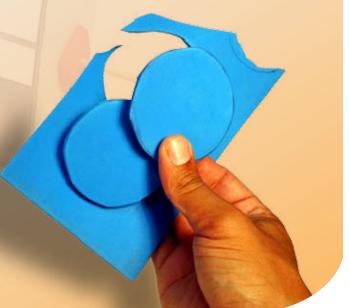
axle

offset cam

Side to Side

cam

axle

pivot

MAKE THE CAMS

Draw your cam and cam follower on the thick Foamie sheet, and cut them out.

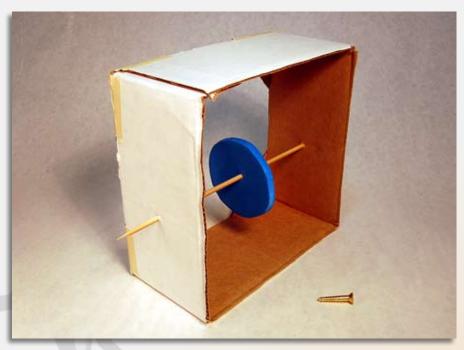The cam should be about 2.5" (6cm) in diameter.

Tip: Cut the cams smoothly, and make sure the cam follower is a little bigger than the cam.

Make the Axle

Put your cam on a skewer stick inside the frame.

Tip: Start the holes in the frame using a nail or screw, and make sure the cam clears the top and bottom of the frame.
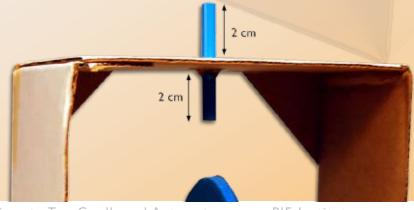
Make the Handle

Glue a small rectangle cut from the cardboard box flap to the skewer stick axle.

Glue a second piece of skewer stick to the end of the rectangle to make a handle.

Add the Cam Follower

Poke a hole in the top of the frame where you want your cam follower to be located, and insert a drinking straw. Carefully glue the drinking straw in place.

2 cm

2 cm

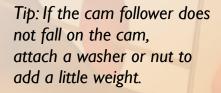*Tip: Use a pencil to make the hole large enough for the drinking straw.*

Glue your cam follower on
the end of a skewer stick
and put it through the straw.

*Tip: The straw will keep the
skewer stick from falling over.*

Test it!

Adjust your cam under the
cam follower until you get the
motion you like, then GLUE
the cam into place on the
skewer stick axle.

*Tip: If the cam follower does
not fall on the cam,
attach a washer or nut to
add a little weight.*

*Tip: If your cam and axle move
out of place, add a small
bushing made from a scrap piece
of a thick Foamie.*

*Tip: Make sure to glue the bushing
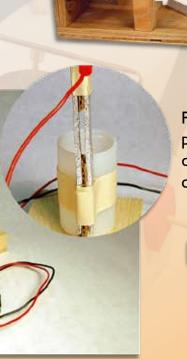to the axle and NOT to the frame.*

TAKING IT FURTHER

You can build automata out of a variety of everyday materials.

MAKE YOUR AUTOMATA COIN OPERATED:

Make a coin detector switch from three popsicle sticks, aluminum foil, masking tape, and a PicoCricket resistance sensor.
www.picocricket.com

Program a PicoCricket to send power to a LEGO motor when it detects a coin completing the circuit in a coin detector.

The skewer stick axle fits nicely into a LEGO motor.

• **A playful and inventive approach to learning simple machines**

This is a playful and inventive way of exploring levers, cams, cam followers, linkages, and other mechanisms.

• **Science and art connections**

Cardboard Automata are a good example of integrating science and art into an activity. For learners, the narrative, decorated aspects of the automata are as important as the mechanical elements.

• **Connections to other activities and the real world**

This activity is a good introduction to a variety of mechanisms and systems found in other PIE activities, and in the real world.

RELATED IDEAS

Peter Markey is an artist who often makes whimsical automata out of wood, utilizing cams and cam followers as his main source of movement.
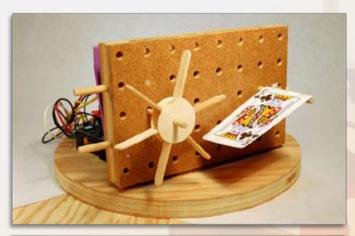
www.focsle.org.uk/first/markey
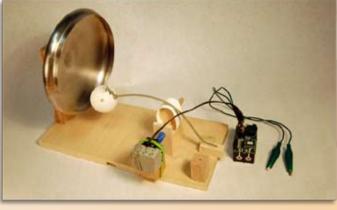www.cabaret.co.uk/artists/markey/htm

The Cardboard Automata activity is a good introduction to another PIE activity called Sound Automata. Sound Automata introduce the idea of creating automata out of everyday objects in order to generate a variety of sounds and noises.

Download the
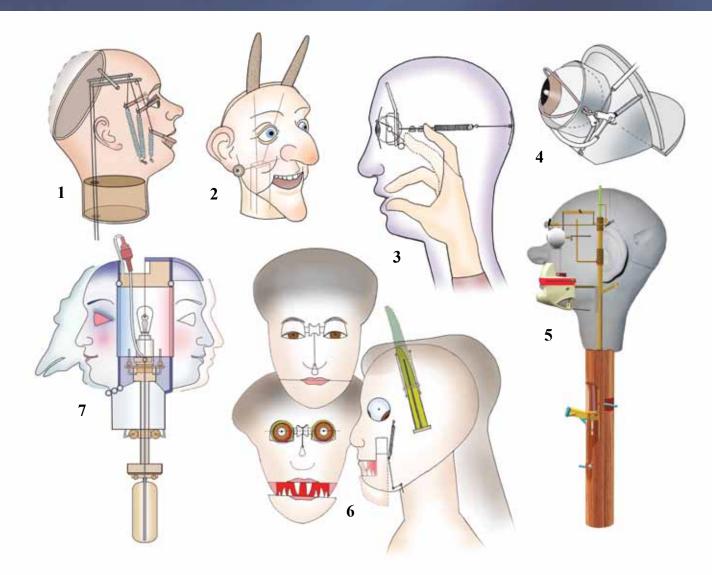Sound Automata Activity PDF
from the PIE website.
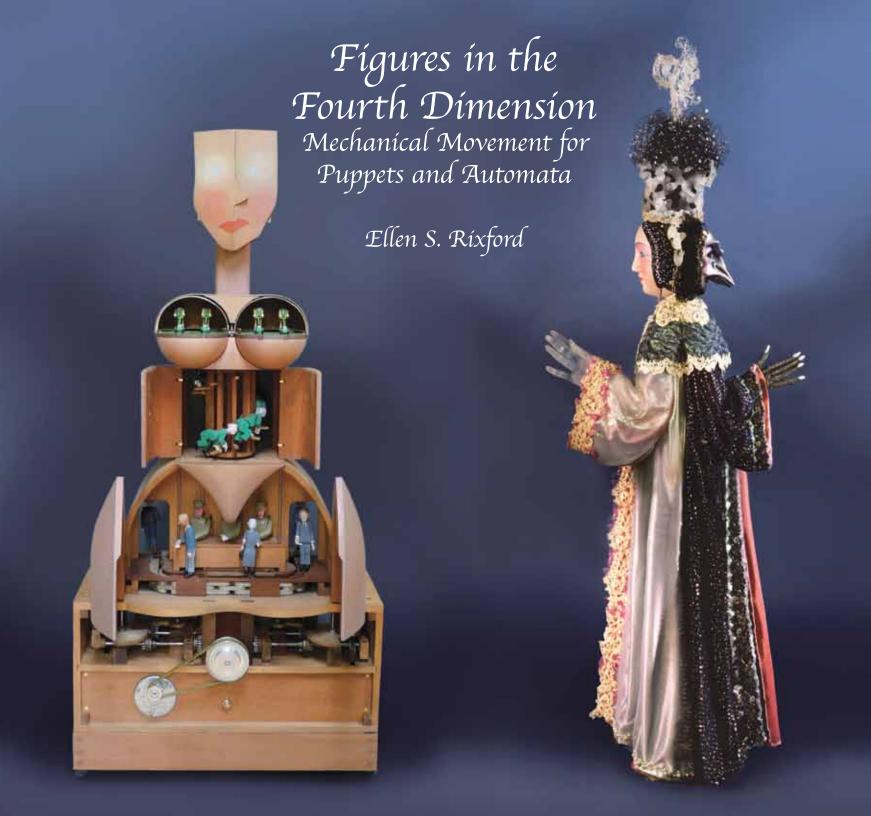
Figures in the Fourth Dimension
Mechanical Movement for Puppets and Automata

Ellen S. Rixford

Some samples of the many technical drawings you will find in this book: Clockwise from upper left: **1**. Gustave Vichy's head of a French peasant, showing eye blinks and flexible lower lip. **2**. Rixford Studio's Judy, with hinged jaw and horns. **3**. Rixford Studio's all-directional rolling eyeballs with blinkers. **4**. Jim Kroupa's eye-roll and blinker assembly. **5**. Dan Lavender's ventriloquist figure head with control stick. **6**. Japanese Bunraku puppet Kiyohime, a pretty maiden transformed into a monster by a dropping lower face section, and reversing eyeballs. **7**. Ellen Rixford's Goddess of Heaven, a double-faced puppet with interior light and masks.

Sample pages from Figures in the Fourth Dimension — as a pdf

This book is a combination volume— a lovingly designed art book, and a meticulously researched technical "teaching" book. It is 512 pages long, all in color, with hard cover and dust jacket. It has over 1500 illustrations — beautiful photographs of puppets and automata in action, and carefully detailed technical drawings of the mechanisms that make them move. The book contains work from three major museums, and over thirty world-class artists from all over the planet. The purpose of the book: to show how to build mechanical devices and linkages for puppets and automata, and introduce these techniques to a readership ranging from the beginner to the sophisticated artist-craftsman. To that end, the artists included in the book had to submit not only excellent quality photos of their pieces (preferably in several positions) but detailed drawings and diagrams showing how the pieces are actually built, and how they really work. In this pdf, you will see, first, the table of contents, listing everything to be found in the book, and then sample pages, showing the artworks, and their technical drawings.

   Because this pdf is meant as a sample only, to give you a good general idea of the book's contents, it concentrates on a few representative pages from each section, and shows their major visual elements. Because of space constraints, the pdf eliminates some of the extremely detailed text explanations and the extensive labeling of the drawings which are present in the actual book. More information at the website figuresinthefourthdimension.com. The book can be purchased at this website, and perhaps at a few other locations. To date, this website is probably the best place to find it. You can also email me at my personal email: ellenrixford@netscape.net.

Cover: At left, Untitled, automaton by Paul Spooner. At right, Goddess of Heaven, puppet by Ellen Rixford. Photos by the artists. Title page: At left, Piano, automaton by Peter Markey, photo by Michael Croft. At right, Thurston, ventriloquist figure by Bill Nelson; mechanics by Dan Lavender. Photo by Walter Gresham.
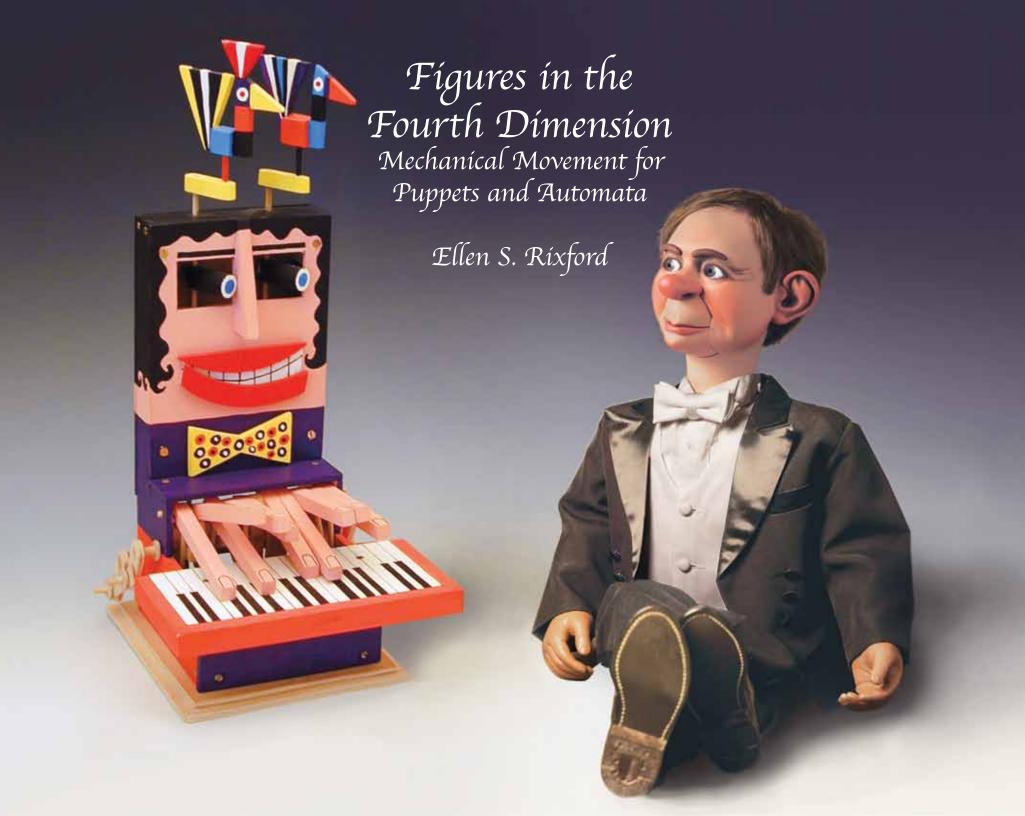
Figures in the Fourth Dimension
Mechanical Movement for Puppets and Automata

Ellen S. Rixford

Table of Contents

Puppets and Puppeteers

"Je ne regrette rien....!"

"Illuminated" Puppets — and Automata

> **Diva,** smoking chanteuse marionette by Phillip Huber: An LED at the end of the cigarette has two wires; one travels through the holder to the end, where a copper wire loop terminates at the mouthpiece. The second wire is threaded through the holder, through the hand, up the arm, through the shoulder and neck, into the head, where it connects to a 12-volt battery. The battery has a wire from the other end that terminates in a copper ring embedded in the Diva's lip. When the end of the holder contacts the ring in the lip, a circuit is completed, the LED lights up, and the Diva takes a drag on her cigarette. 28" tall. Wood, Celastic, theatrical fabrics, wire, epoxy putty, sheet stainless steel, and brass tubing. 2015. Photos, the artist.

Vintage Training Robotic Arm, by Pablo Lavezzari. 45" x 23" x 30". Wood, glass, copper, bronze, paper. 2014. For private collector. Photo, the artist.

Modern Automata:

In this section, there are varying levels of difficulty. To make things easier, I suggest four levels.

*= fairly easy to understand, **=moderately difficult, ***=complex, •=very complex.

Mechanical Face by François Junod. Eyes move right/left, eyelids blink, eyebrows pivot from angry to anxious, mouth corners widen into a smile, or purse together for a kiss, hair is pushed up/down and returns on extension springs. 40 cm. Poster for 40th anniversary of the CIMA museum, and cover for the Patek Phillippe journal. Photo courtesy of the artist.

Clockwork Automata, Modern and Historical

These machines are powered entirely by a mainsprings. and regulated by either fan-bladed governors, or by escapements.

The website for this book, figuresinthefourthdimension.com, contains some supplementary information, images and an ebibliography that is far more extensive, with many more sites, than the one offered in this printed book.

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Pierrot Writing, by Gustave Vichy. A sleepy Pierrot "writes" a letter to his Columbine, turning up the gaslight as it dims. 25" x 21½" x 14". Wood, papier maché, steel, brass, leather, gesso, oil paint, various fabrics. 1895. Photo, the Guinness Collection, Morris Museum
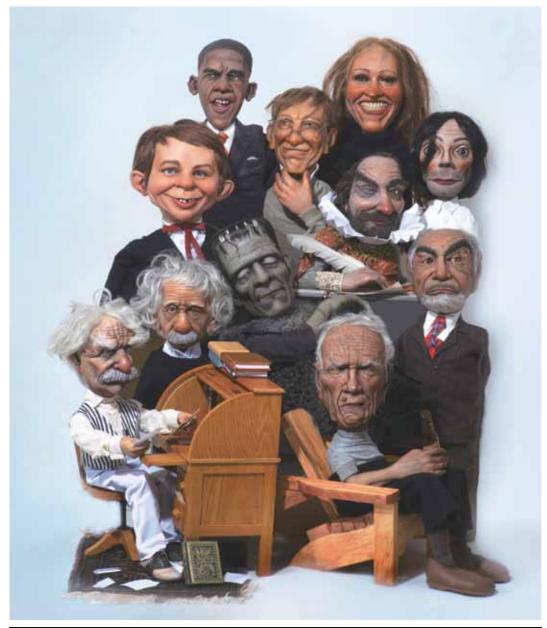
Bill Nelson's group portrait of celebrities: Barack Obama, Bill Gates, Julia Roberts, Alfred E. Neuman, Will Shakespeare, Michael Jackson, the Frankenstein monster, Sean Connery, Mark Twain, Albert Einstein, and Clint Eastwood. At right, series of assorted funny-face vent figures from Inspired Worx, collaboration between Bill Nelson and Dan Lavender.

Basic Mechanics

Power sources

At the beginning of mechanical movement is the source of power; it is what, if you like, sets the magic in motion. The puppeteer can bypass a good many of the problems which must be solved by builders of other kinds of mechanical figures; instead of needing to install a built-in power source which will drive and coordinate movement, the puppeteer directly connects to the figure in real time. Usually it's hands. Hand puppets, the most simply constructed of all little actors, use but three fingers for head and both arms. Even so, some hand puppets can be built so the head-finger can manipulate an opening mouth. For larger and more complex puppets the puppeteer can use various convenient body parts — fingers, hands, arms, sometimes legs, feet, torso, head, especially if the limbs of the puppet are connected directly to the manipulator's. Marionettes are held up by strings and a control; rod puppets, including ventriloquist figures and the Bunraku puppets of classical Japanese puppet theater, are mounted on and manipulated by vertical rods, or "head sticks," often with triggers powering individual features. As many as three puppeteers, shrouded in black, and standing behind the puppet, are required to give the more important Bunraku characters their delicate and expressive gestures. The master puppeteer manipulates the head, often with mechanical facial features, another puppeteer works the hands, a third controls the feet.

Some large modern puppets are mounted on body harnesses to distribute weight. Some puppets have their bodies locked to the puppeteer's, their hands and feet connected to the puppeteer's hands and feet, so the puppet closely imitates the puppeteer's movements. Large puppets can even morph into full body costumes worn by the puppeteer. Muppet-style puppets' heads have facial features worked by one of the puppeteer's hands inside the head, while the puppet's hands are worked by rods held by the puppeteer's other hand. If the puppet has to do complex hand movements, like playing the piano, a second puppeteer wears gloves that look like the puppet's hands, "Fozzie Bear" style. Whatever the form of connection, the puppeteer is in complete control of timing, and can decide whether, when, and how much to move a feature, or combine movements.

For the automatist, there are additional problems.

1. The figure isn't manipulated by the artist, so it has to be powered by a self-contained power source. The three major power sources are hand cranks, motors, and, mostly for the antique automata of the pre-electric age, clock-work — a strong mainspring, contained within a barrel. There are a few external sources: an occasional sand-powered automaton, the delicately balanced
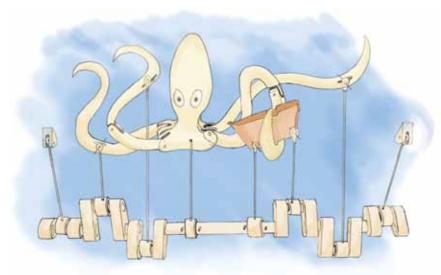
Kiyohime: Bunraku character of a maiden who becomes a monster because her amorous advances are rejected by a Buddhist monk. ⅔ life size. Wood, human hair, whale baleen for spring return. Her eyes reverse, becoming bloodshot staring orbs, her jaw drops down revealing a set of pointed teeth, her horns extrude — all at the pull of a lever. Traditional puppet by master puppet builder Toru Saito. Both photos by Mr. Saito. Other photos, technical drawings and a detailed description of possible ways to build the mechanics for these movements appear in the next section—on mechanical devices..

mobiles of Alexander Calder, and recently, the wind-powered perambulating Strandbeests of Theo Jansen. While there is no reason why many new automata couldn't be powered by wind, water, changing magnetic fields, solar power, or even sand, these are, at present, exceptions.

2. Because timing, type and quality of a figure's movements are controlled internally as well, the automaton must rely on a whole series of mechanical devices to help it perform. I will describe them in order of simplicity, and explain their connections to each other. In writing about mechanical movement, there is a general term: **"linkages"** which is often used rather vaguely to describe mechanical devices in general. Linkages do link mechanical devices, transferring motion between them. But as there are a great many devices in mechanics, this can lead to confusion as to which device is technically a linkage. So for clarity, here "linkages" will mean those devices or combinations of them

If the drive shaft has bends in it, it becomes a crank shaft. When the drive shaft ends in a bend with a handle on the end of it, that is a crank handle, powering the automaton. Cranks and crank shafts are normally used when one wants to change direction from rotating to reciprocal motion — back and forth, side to side, or up and down. The bigger the bend in a crank shaft, the bigger the reciprocal motion. Cranks can be bent rods; crank shafts can be bent rods or combinations of rods, straight and/or bent. The bends are not always straight 90° angles, either. Curved or wavy bends (often made with wire) can result in a beautiful reciprocating wavy movement, like surf in a mechanical seascape, or the writhing of a mechanical snake or dragon. Cranks can be power sources, or links which transfer power to something else They can change the direction, dimension, and effort needed for a movement. When the crank is used as a lever turning the drive shaft, the length of its handle increases force or torque, making it easier to rotate the automaton's drive shaft. Many automata, even quite complex ones, are hand cranked. Nearly all automata contain some form of crank or crankshaft within their mechanics. And cranks and crank shafts offer many possibilities to the puppeteer, who can rotate a pair of eyeballs, raise or lower eyebrows, or swing open a pivoting jaw by connecting these linkages to cranks plus push-pull rods or pull-cables inside the puppet's head.

Here Be Monsters, by Wanda Sowry. Drawing of a crank-operated crank shaft powered writhing giant squid doing dreadful things to a lifeboat. 35 x 30 x 12 cm. Wood, 2005, Collection, the artist, who also did the drawing. See more details on this piece in the chapter on Sowry's work.

Levers

Levers are pivoted rods; the pivot here is called the lever's **fulcrum**. They appear in nearly every automaton, and in many puppet mechanics as well. They can help marionettists by vastly extending the "reach" of a movement on a control; they often serve the automatist as "rider-followers," transmitting motion from one device to another. Most often they are straight, but can also be bent; in French they are called a **"levier coudé"** or "elbowed" lever and in English, a **bell crank**, illustrated in the following pages. As discussed below, a bent lever or bell crank will, instead of moving something at a 180° angle, move it at a different angle, depending on the angle of the bend. It can also change distances.

There are three types, or classes, of levers.

A class one lever consists of a bar with the pivot point or fulcrum in the middle, the force moving the bar at one end and the load, or weight of something to be moved, at the other. When the force applied and load are equal, or perfectly balanced, that is equilibrium — no change in movement. When either the force or the load increases or decreases, equilibrium is lost; there is movement. Levers can vary the relationship between the force needed to move a load and the weight of the load, depending on the placement of the fulcrum. Using a lever, and placing the fulcrum or pivot appropriately, a small force can move a very large load. A longer distance between the fulcrum and the force and a correspondingly short distance between fulcrum and load proportionally increases the **mechanical advantage**, or the ratio of load/force. The greater the distance the greater the weight or number of units of load that can be moved by one unit of force. And vice versa. Examples of class one levers: children's see-saws, a long crowbar prying up a heavy rock; scissors, pliers, bolt cutters where the hinge is the fulcrum, the material being cut or squeezed is the load, and the force is the hand.

A class two lever has the fulcrum at one end, the load in the middle, and the force at the opposite end. Because in this configuration the distance between the fulcrum and the force must be longer than the distance between the fulcrum and the load, this kind of lever always results in positive mechanical advantage, less force moving more of a load. This kind of lever is useful for devices needing to greatly lessen the force needed to move a given load: nutcrackers, wheelbarrows.

A Class three lever also has the fulcrum at one end, but the force is in the middle and the load is at the end. Here the distance between the fulcrum and the force is shorter, resulting in a mechanical advantage of less than one. This kind of lever is useful if not much force, but greater precision is required; example: a pair of tweezers. Class one and class two levers are very frequently used as followers in automata, and often appear as part of puppet mechanics and controls as well. Class three levers appear less often, but can be useful when one wants to "step down" the level of force for a very small, delicate movement.
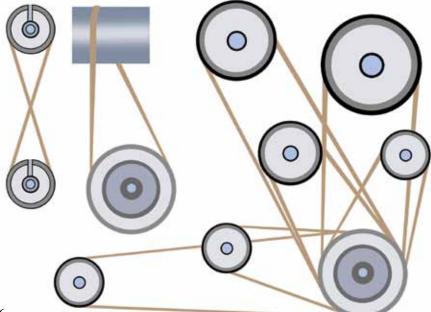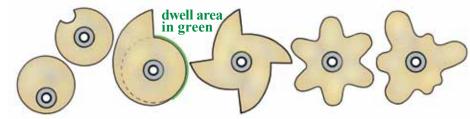
Big Wave, by Peter Markey. Storm-tossed seascape made entirely of first class levers. The left-hand set of levers transmits the motion from a lineup of staggered cams just underneath them on the left side. (See more on cams in cam section.) The left-hand set of levers is a little heavier on the left than the right, keeping them in contact with the cams. The right-hand levers, because they are heavier on their inner or left-hand ends, act as counterweights keeping all the ends of the bars in contact, and acting on each other. The middle set of levers are in equilibrium and follow the actions of the outer sets. A tiny ship rides the tossing middle set of lever "waves". Size is about 30 cm. wide, 30 cm. deep, 50 cm. tall. Sculpture is of wood — fir boards bought in ready-made sizes from do-it-yourself shops; the paint is also do-it-yourself water soluble acrylic based emulsion for house walls. Cabaret Mechanical Theatre. Credit, Falmouth Art Gallery, Collection, Falmouth Art Gallery. Photo, Steve Tanner.

Pulleys

They are wheels connected to other wheels via belts. The wheels can be made of any hard material (for example, wood, plastic, metal) and the belts can be any strong and flexible connector (for example, leather, nylon or rubber). One wheel turns the other due to the friction generated by the belt rubbing over the wheel edge and pulling it around. Thus, pulleys are classified as **friction drives**. The wheels can have various kinds of edges — most often concave rims at the wheel edge or a simple groove to hold the belt, increase friction, and keep it from slipping off. A common use for pulleys in automata and puppetry is transmitting rotational movement from one part of the piece to another part, or to several other parts. A primary pulley wheel on a drive shaft, rotated by the crank that powers the automaton, can be connected via one or several wheel and belt combinations to secondary wheels or shafts in other parts of the piece, causing many parts to rotate at once. If the pulley wheels are of different sizes, they rotate at varying speeds. If the pulley wheel at the beginning of the sequence is a large diameter one, say one foot, and the wheel (or shaft) belted to it is smaller, say, one-fourth the diameter, or three inches, one rotation of the first pulley will result in four rotations of the smaller one. In ALL rotating devices: pulleys, friction drives, gears, increasing the rpm speed of any wheel-related device proportionally decreases force; decreasing speed increases force. In automata, this is a major consideration. Some parts of a mechanical movement need to turn with more force to power heavy mechanical devices. Other parts need a very light force so they can be easily braked.
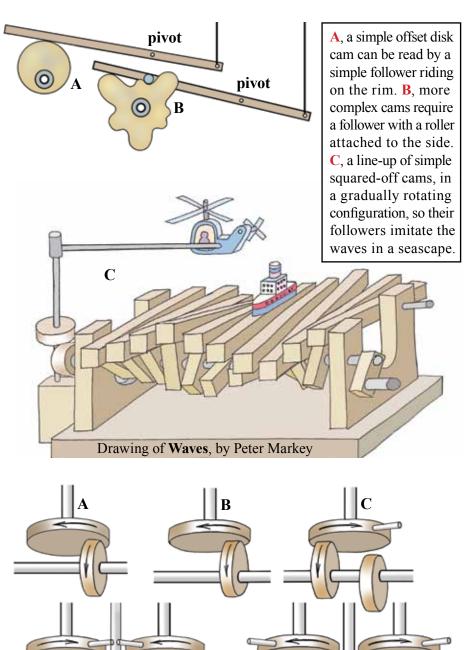
Varying cam profiles: Left to right, an eccentric; a cam used as a switch; a nautilus (green line on the nautilus indicates **dwell,** the time when the cam, turning, will not influence movement because its throw doesn't change); then a four-pointed nautilus (four sudden movements); a daisy/flower petal, and an irregularly-lobed cam. Infinite varieties of cam profiles are possible. Profiles depend on the kind of movement the automatist wants to produce.

Cams
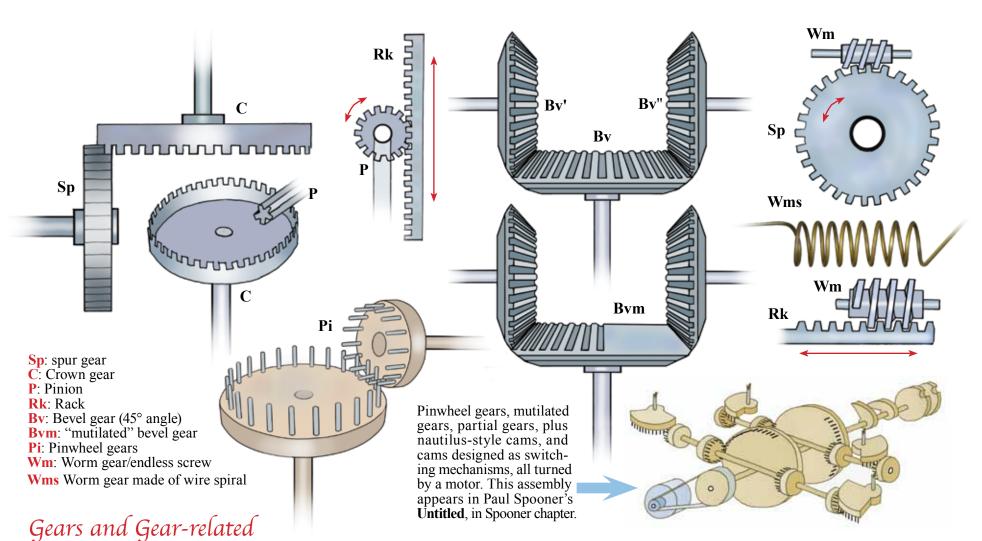
While the crank and shaft give fairly simple reciprocal movements, the cam offers possibilities for more complex movements, with more variety. Cams are disks, usually but not always two-dimensional, whose shapes or **profiles** modify movement as they rotate. They are used to control the nature and timing of movement. Cam profiles can come in any number of variations. The simplest are **eccentric** or off-center cams — a disk with an eccentric center pivot. Then come egg-shaped, heart-shaped, and multi-lobed shapes, sometimes called daisy cams because their shape reminds one of flower petals; and the so-called **nautilus** or **snail** cam, because of its resemblance to the shell. The nautilus cam has a gradually rising profile which suddenly drops back to the point nearest the center. If you measure the distances between a cam's center pivot point, and the cam's edges, you will get the **throw** of the cam. It is the difference between the shortest distance pivot-to-edge, and the longest distance pivot-to-edge. This would be the distance something attached to or resting on the cam would travel back and forth as the cam rotates. In the case of the eccentric circle, egg-shape or oval shape, the distance gradually increases and decreases in a regular pattern. The eccentric circle and egg-shaped type of cam will give gradual movements from one point to another — one cycle per revolution of the cam: an arm rising and falling, a head or body turning, wings unfolding and folding, a box or a door opening and closing, a mask removed and replaced. The nautilus cam's profile results in a gradual movement in one direction followed by a very sudden movement in the other: an executioner raising his axe and suddenly bringing it down to chop off a head, or a lion snapping off the head of a circus performer. This kind of cam can also be used as a **switching mechanism**. Another very simple switching device is a disk cam with a little "bite" taken out of it. **Multi-lobed** profiles result in many movements back and forth per cam revolution.

A, a simple offset disk cam can be read by a simple follower riding on the rim. **B**, more complex cams require a follower with a roller attached to the side. **C**, a line-up of simple squared-off cams, in a gradually rotating configuration, so their followers imitate the waves in a seascape.

Drawing of **Waves**, by Peter Markey

A Transport of Delight, by Keith Newstead. Rods and cables, connected to attachment points on the wheels make the driver pedal and move the handlebars, and wave the bat wings. Size: 12" x 8" x 15". Wood, brass, wire, acrylic paint. July 1999. Private collector. Photo, Keith Newstead.

Rk
C
Sp
P
Bv' Bv''
Bv
Wm
Sp
Wms
Wm
Rk
Bvm
Pi
P
C

Sp: spur gear
C: Crown gear
P: Pinion
Rk: Rack
Bv: Bevel gear (45° angle)
Bvm: "mutilated" bevel gear
Pi: Pinwheel gears
Wm: Worm gear/endless screw
Wms Worm gear made of wire spiral

Pinwheel gears, mutilated gears, partial gears, plus nautilus-style cams, and cams designed as switching mechanisms, all turned by a motor. This assembly appears in Paul Spooner's **Untitled**, in Spooner chapter.

Gears and Gear-related

Remember the sprocket wheels and chain which appeared a few pages ago, along with the text and illustrations about pulleys? Where pulleys and other kinds of friction drives engage using surface-to-surface friction, positive drives engage using interlocking teeth. The teeth on the sprocket wheel receive or impart force as they lock into the links in the sprocket chain. The teeth in gears lock into the teeth in adjoining gears, or in another corresponding part. There are many kinds of gears. Industrial gears come in almost every conceivable kind of shape and size, including eccentric, elliptical, intermittent, hollow, and sun-and-planet. The above illustrations offer only a partial list, but they are the ones most commonly used in kinetic sculpture. A **spur gear** is a medium-sized gear, a fairly standard disk shape, with teeth spaced evenly around its rim. Occasionally, when two or more adjacent spur gears of the same or similar size are needed for a movement; they are placed so that one drives the others. The "extra" driven gears are called **idler gears**; they don't contribute any power to the actual gear sequence, but they are necessary to drive linkages connected to them. A spur gear is frequently paired with a **pinion**, a smaller-sized gear adjoining it, or on the same shaft. **Spur gear-and-pinion combinations** are often used in **gear trains** to speed up or slow down rotation and change force (torque) ratios. (See following pages.)

Changing the plane of rotation: Gears that mesh at a 45° angle, called **miter gears** if their diameters are the same, or **bevel gears**, if their diameters are different, change the plane 90°. Many automatists building gears in a home

Olympia, by Paul Spooner. 24 cm x 16 cm x 100 cm. Wood, steel wire, brass, painted in acrylic. Photo of the piece by Gary Alexander. Drawing by Paul Spooner. Collection, Cabaret Mechanical Theater. The pinwheel gears visible in the drawing, are also visible under Olympia's couch. Spooner cleverly uses the tail on the leopard couch as a crank!

workshop resort to **pinwheel gears**, a clever alternative to the manufactured kind. Here, pins are glued into disks at regular intervals. The intervals must be very carefully spaced for the gears to engage smoothly, and the disks should be made of very hard and durable materials, so the constant stress on the pins won't loosen them. Pairing a spur gear with a **worm gear**, or **endless screw** also changes direction; this combination is frequently used in clockwork automata, where the screw gear is on a long shaft terminating in a fan blade, which slows down the speed of the automaton's mechanism. (See section on governors.) In the home workshop, a spiraled wire can take the place of a "store-bought" worm gear. Pinions and worm gears, paired with **racks** (as in **rack-and-pinion** combinations) change rotary motion into lateral movement.

This is useful in providing a slider motion, an automaton raising his hat, or a figure with an extending body, limbs or nose.

Intermittent motion: Sometimes it's necessary to temporarily stop a movement or to alternate movements. Simply removing the teeth from a gear can accomplish this. This device, called a **mutilated gear**, can stop the movement of one part of a mechanism while the other parts remain in motion, and stop motion in varying proportions, depending on the ratio of teeth that are removed from a gear. As in the diagram of the **Untitled** pinwheel gear assembly on the adjoining page, removal of all but ⅓ of the teeth in the large pinwheel gears mean that at any given time during the automaton's movement, ⅓ of the whole mechanism will be moving while the rest remains stationary.

1

2

3

4

5

6

7

"A Spring and a String....."

.......is Jim Kroupa's light-hearted summary of his work. Here, a collection of his puppets, various sizes, for various clients. The drawing at right shows a general control design. The puppets use variations on this theme.(See the Kroupa chapter for more information.)
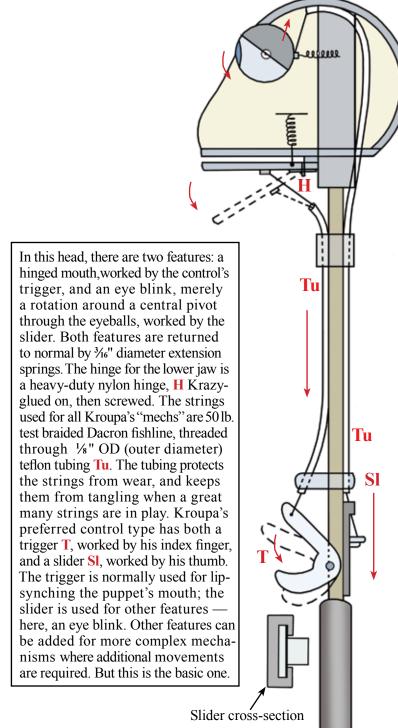
1, **Blue Guitar Player**: One of a bug rock group called the Beetles. About 9" tall, his body is made of blue fake fur, with plastic dome eyes, and pipe-cleaner antennae. His jaw is hinged, and he has a lip-synch trigger on his control rod. His arms are long skinny extension springs, which jiggle at the slightest touch This puppet was made in 1999 for Kroupa's birthday party show. The Beetles sang to sped-up versions of pop songs, so that the music sounded like it was being sung by a chorus of insects.

2 and **3**, **Santa, Grumpy and Happy**, made out of urethane foam and fleece in 2014 as a teaching project for the O'Neill Puppetry Conference. Santa's hat tilts up, showing his eyes, his head turns left/right, and his mouth lip synchs on a small hinge. Kroupa's signature slider/trigger control powers the "mechs;" the slider raises the hat, the trigger synchs the mouth, and the head is turned by turning the central rod. The arms are worked by arm rods.

4, **The Booger**, made for a show pitch to the Cartoon Network for a show that never happened, this 6" tall character is fished out of giant child's nose, crying, "Don't eat me! Please don't eat me!" and is summarily wiped off on a chair seat, where he contemplates in amazement the giant (schoolroom) world around him. The body, made of various plastic parts, with mismatched dome eyes, and surfaced with suitably sculpted hot glue blobs painted in green acrylic, is on a tube, through which the control rod passes, for a piston-type control. The control, made of a circular disk on the rod where the handle would normally be, moves his head up/down and left/right, his mouth lip synchs thanks to a slider on the lower part of the control rod. The little shirt was stolen from a Ken doll.

5 and **6**, **Eugene, the Snail**: This 9" snail was one the cast of characters for a TV series, Johnny and the Sprites. Johnny is young man who lives in a house in a magical place in the forest, inhabited by sprites. Eugene is one of Johnny's friends — the "slowest" of them. The snail is made of foam and fleece, with plastic eyes whose eye stalks can extrude from the body and turn left/right. His little wings, on pivots, can open and close. His shell is carved from dense hard foam, the kind put in football helmets, surfaced with a skim-coat spackle putty, sanded and painted in acrylics. The eye stalks are spring steel wires covered in fleece, which are mounted on a wooden dowel, and pushed up/pulled down through a bike cable housing. Twisting the dowel left/right swivels the eyes left/right. The lip-synched mouth is worked by a trigger on the control, the wings by a slider.

7, **Peanut Butter and Jelly Sandwich**: This puppet, the size of an average sandwich, was done in 2004 for "Between the Lions," a TV series for Public TV, as part of a children's story, teaching children about food. The "bread" is urethane foam, the "peanut butter and jelly" are hot glue painted in acrylics. The eyes are made of plastic domes, with pupils that move left/right via a slider on the control. The trigger lip-synchs the mouth.

In this head, there are two features: a hinged mouth, worked by the control's trigger, and an eye blink, merely a rotation around a central pivot through the eyeballs, worked by the slider. Both features are returned to normal by ¾₆" diameter extension springs. The hinge for the lower jaw is a heavy-duty nylon hinge, **H** Krazy-glued on, then screwed. The strings used for all Kroupa's "mechs" are 50 lb. test braided Dacron fishline, threaded through ⅛" OD (outer diameter) teflon tubing **Tu**. The tubing protects the strings from wear, and keeps them from tangling when a great many strings are in play. Kroupa's preferred control type has both a trigger **T**, worked by his index finger, and a slider **Sl**, worked by his thumb. The trigger is normally used for lip-synching the puppet's mouth; the slider is used for other features — here, an eye blink. Other features can be added for more complex mecha-nisms where additional movements are required. But this is the basic one.

Slider cross-section

Jim Kroupa's iconic puppet Taxi dog, best friend of a New York taxi driver, this puppet has multiple moving facial features: eyes, eyebrows, tongue, teeth and ears. Puppet is the size of a mid-sized dog. Media: ABS plastic for skull parts, custom-made resin eyes, various radio control parts, such as ball links and steering arms, architectural model parts, such as I beams for slider control, mechanical parts such as thrust bearings. (See more information on Materials and Tools in the Basics chapter of this book.) © Taxi Dog Productions, LLC. Photos by Jim Kroupa, drawings by Jim Kroupa and Ellen Rixford. Opposite page: four views of the finished cranium, all "mechs" installed from: 1. front, 2. side 3. below and 4. above.

1 **2**

4 **3**

Facing page: Joseph Cashore's marionette Cyclone the Horse, grazing. This page: control for the horse This puppet captures the movements of a flesh-and-blood horse in such an expressive and lifelike manner as to be as "horsey" than the real thing. 24" tall. Wood, papier-mâché, leather, brass tubing, music wire, springs, epoxy putty, ostrich plumes, lead weights, acrylic paint, various adhesives. 1992. Collection, the artist. Photos of the horse and controls, Ellen Rixford. Drawing of controls, Joseph Cashore.

Main control: This structure controls the body of the horse. The shoulders and hip strings carry the weight of the puppet. It also controls some of the leg movements, and the tail. Two auxiliary rods, which attach via Velcro strips to the diagonal shaft, (1) fold legs in front, for a kneeling position, (2) and pull up the front of the horse's body, allowing him to rear up. Sliding horizontal rods, ending at the back end with a counterweight, and in front with epoxy putty and hook for head control, extend the horse's neck for galloping position.

Leg controls: This section of the control is hinged in the middle and moves through an arc of 180° to reconfigure the leg control for galloping. It controls various leg movements through strings attached to fore and hind leg joints, and spring returns controlling hoof movements. In some positions, as when the horse rears up, this is attached by the Velcro on the horizontal crossbars to the Velcro on the perch, to free the puppeteer's hands for manipulating other parts of the control (dotted lines).

Below is the section, made of bent wire, devoted to the head, controlling head position and movements of the features. The bend in the wire at the middle of the control allows this to be hung onto the hook at the front of the main control. (Follow dotted line)

Two auxiliary rods, temporarily attachable by Velcro strips

Note: as this control is very complex, the smaller details of individual parts are illustrated in the following pages where the parts of the control are shown larger.

25

Mo Sho Long – Magic Dragon Magician: This very complex marionette goes through many transformations. His magic wand magically produces a bird-kite, which flies around the stage before flying away. His fan releases a flock of butterflies, flying away with them all. His costume raises to form a puppet stage upon which two small figures engage in a fierce battle, then a golden ball materializes above his body and metamorphoses into Magician's own face. At last he is transformed into a fire-breathing dragon prancing about the stage. He is 22" tall, made of Celastic, wood, epoxy putty, aluminum sheet, wire, and various fabrics. Completed in 2013. Collection, Huber Marionettes. Photos of disembodied head and dragon emerging from the body, and dragon breathing smoke, Richard Termine. All other photos, the artist.

Phillip Huber's magical puppet performance, which inevitably brings audiences to their feet, cheering, took years to develop and perfect. Huber learned some of the magic tricks used here at Magic Castle, an exclusive magician's club in Los Angeles, California. Members were asked to swear **never ever** to reveal secrets they learned there. For this reason, much in these pages, dear reader, is left up to your imagination. If you look very carefully at the excellent photos the puppeteer and photographer have provided, however, perhaps you can deduce how some of these wonders are created.

26
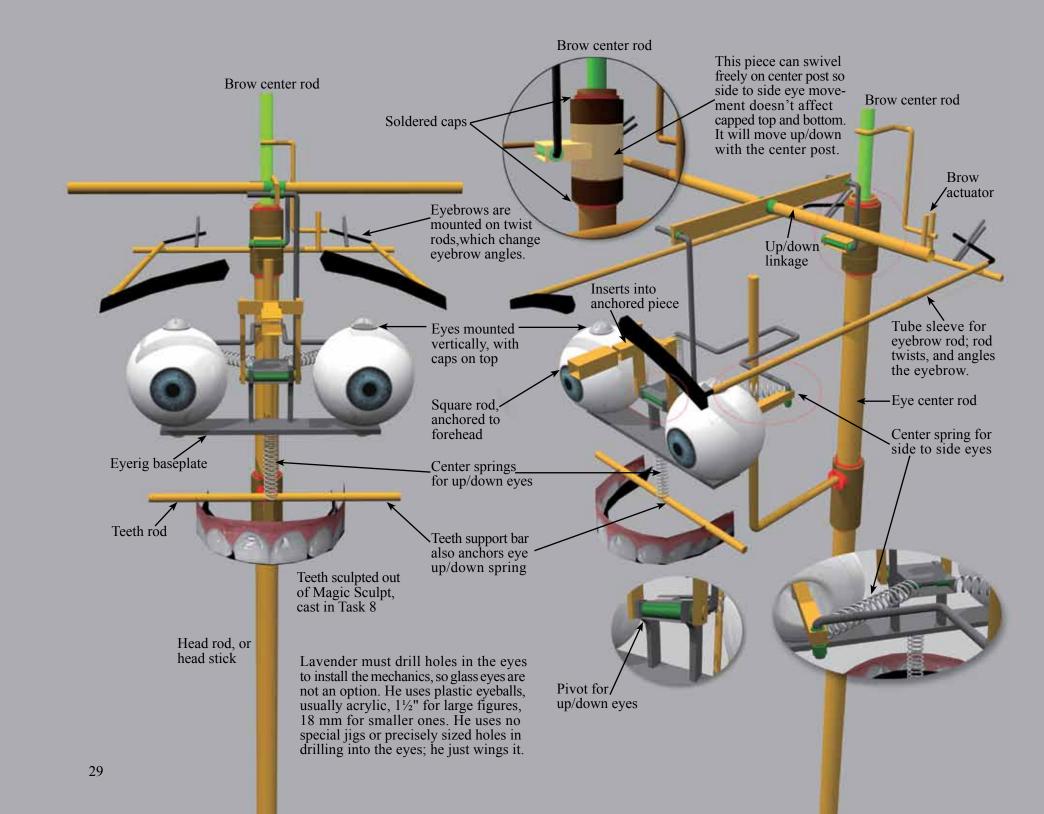
Initially, the Magician's face is painted black and white, to look like a character from the Peking Opera. This is significant, as the colors and styles of face painting represent different personalities. White symbolizes craftiness; black, seriousness and strength. Now he appears holding a wand. A bird-shaped kite suddenly appears tethered to end of the wand and flies around the stage, eventually flying off-stage, taking the wand with it. Kites shaped like birds, butterflies, and flying deities are a tradition in China.
Can you imagine how his holds the wand, and where the kite comes from?

The Magician lifts the apron of his costume, hiding his face, and creating a miniature theater for two miniature hand puppets, who are battling each other with sticks. The symbol on the back of this apron means "Dragon" in Chinese. And the Magician's Chinese name is Mo Sho Long — meaning Magic Dragon. The hand puppets descend behind the stage and disappear, to be replaced by a golden ball, mysteriously floating above the apron. The ball transforms itself into the sweetly smiling face (on the disembodied head) of the Magician.

Mo Sho Long's head has disappeared! Now, out of his body emerges a dragon, breathing smoke, and prancing about the stage. The discarded body is cast off, and disappears. Huber often found it necessary to build several alternate mechanisms, experimenting again and again before finding one that worked perfectly and reliably. This creation is more than a technical marionette — it is a carefully staged series of magic tricks — theatrical illusions meant to perplex and amaze an audience.

27

At left: Thurston, vent figure by Nelson/Lavender. Above, the full mechanical movement for the puppet's facial features. Figure is 38" tall; face and hands originally sculpted in oil-based clay, then fabricated in cast resin, with mechanical parts, wig hair, and fabric costume. Completed 2012, for a private client. For this chapter, unless otherwise credited, photos of the completed figures are done by Walter Gresham. Drawings and photos of the mechanical parts and movements and the accompanying explanatory text are all done by Dan Lavender.

Brow center rod

Head rod, or head stick

Brow center rod

Soldered caps

This piece can swivel freely on center post so side to side eye movement doesn't affect capped top and bottom. It will move up/down with the center post.

Brow center rod

Brow actuator

Eyebrows are mounted on twist rods, which change eyebrow angles.

Up/down linkage

Inserts into anchored piece

Tube sleeve for eyebrow rod; rod twists, and angles the eyebrow.

Eyes mounted vertically, with caps on top

Eye center rod

Square rod, anchored to forehead

Center spring for side to side eyes

Eyerig baseplate

Center springs for up/down eyes

Teeth rod

Teeth support bar also anchors eye up/down spring

Teeth sculpted out of Magic Sculpt, cast in Task 8

Pivot for up/down eyes

Lavender must drill holes in the eyes to install the mechanics, so glass eyes are not an option. He uses plastic eyeballs, usually acrylic, 1½" for large figures, 18 mm for smaller ones. He uses no special jigs or precisely sized holes in drilling into the eyes; he just wings it.

29

Corbian Arts puppets, with various characters: two giant birds, Phaedra, the tall bird, Verla, the green ostrich-like bird, a fish, Darwin the Dinosaur, and a giant flower that has sprung from the dinosaur's droppings. Opposite page: giant fish in swirl of water.

The puppets: varying sizes, from a third life size to over 14' tall. All puppets made from electro-luminescent wire sewn into fabric costumes utilizing aluminum wire, epoxy rods, foam padding, various fabrics, backpacks, springs, and various electronic parts. (See following pages.) Puppets built 2006-2012, and ongoing. All puppets: cast of Corbian Arts. Photos for this section, Corbin Popp, Ian Carney, Stephen Charles Nicholson, Eleanor Carney, and Whitney Popp. Technical drawings, Corbin Popp. Electronic diagrams, Ellen Rixford. Pictures of the cast members include Stephen Charles Nicholson, Eleanor Carney, Ian Carney, Michael Quintana and Tierney St. John.

Diagram showing El-wire construction and placement of power source, dimmer, driver/inverter, hot (red) and ground (black) wires.

Exactly the same setup with two El-wires of different colors

Set-up for a stage set switching between two dimmers and multiple driver/inverters

Wall plug and wires

Power source (battery)

Switch

Dimmer

Driver/Inverter (DC to AC)

Connector(s) to El-wire(s)

Setup for switching between two different colors of El-wire

El-Wire: construction: consists of five components. At the center is a solid copper wire, coated with phosphor. Next is a layer which isolates this copper wire core from a very fine copper wire which is spiral-wrapped around it. Around this sandwich of phosphor coated copper core wire, isolating layer, and wrapped thin copper wire is a clear PVC sleeve. Around this sleeve is another colored translucent or fluorescent PVC sleeve. When an alternating current of about 90 to 120V at about 1000 Hz is applied between the copper core and the fine wrapped copper wire, it acts as a coaxial capacitor, having about one nF of capacitance per foot. The rapid charging and discharging of this capacitor excites the phosphor to emit light. Colors produced in this way are limited. When excited, the core produces blue-green light. But fluorescent organic dyes added to the clear PVC sleeves can produce reds and purples.
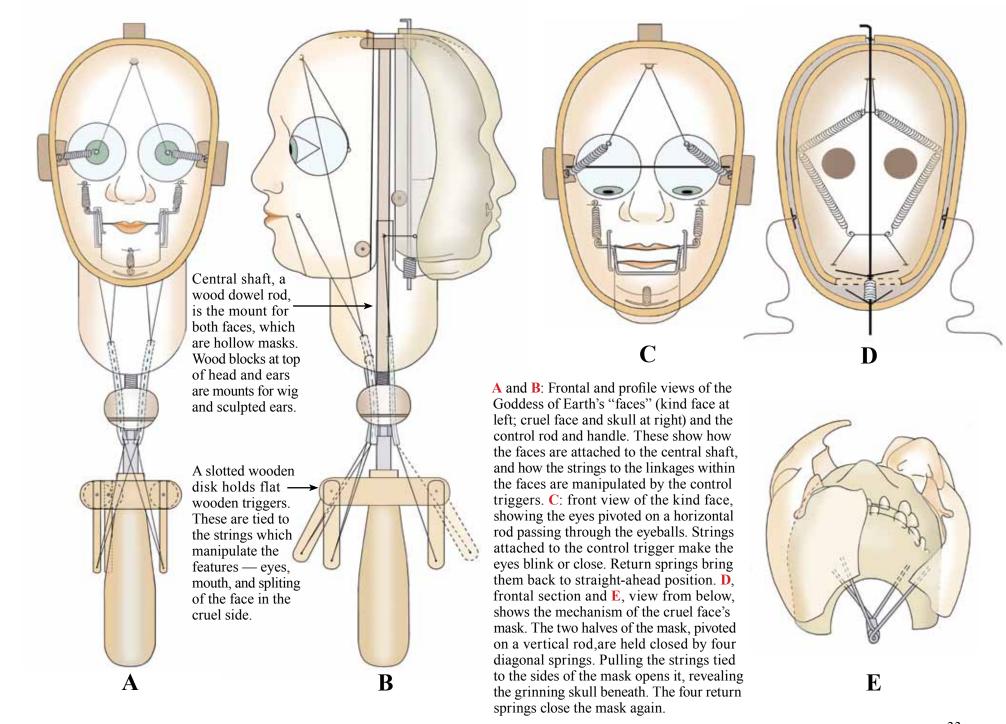
To generate the high-voltage drive signal from a small power source (AA battery pack of 7-12V) a resonant oscillator (driver/inverter) is used. Because of the capacitance load of the El-wire, the inductive, or coiled transformer makes the driver a tuned LC oscillator, thus very efficient — so efficient that a few hundred feet of El-wire can be driven by an AA battery pack. (With thanks to Wikipedia)

"The setup requires a battery source of about 12V, a DC dimmer, an inverter to change the power to AC, and the El wire load. We have struggled for years to find a smooth dimming system — three professionals and dozens of dimmers that dim DC circuitry. The ability to dim is a way to express emotion and make things appear or disappear smoothly. Connecting backgrounds to individual characters, changing scenic elements requires advanced dimming. Being able to set a timed 'push button' dimmer would allow dimming by a character without his needing to manually twist the dimmer control while busy acting. The manual dimmers that work best are either from an LED dimmer or a marine 12V dimmer. We hear that the dimmers made by the pros (the guys over at RC4 wireless (**www.theatrewireless.com**) won't work to theatrical standard due to the poor engineering of current inverters. Many inverters for El-wire can emit annoying high-pitched sounds which detract from a theatrical performance. We have yet to see our medium perform perfectly. The search goes on......."

Goddess of Earth, or Mother Nature—kind and cruel aspects, by Ellen Rixford. This Bunraku style double-faced puppet was built shortly after a trip to Japan, where I was introduced to the Bunraku art form by friends. I was deeply impressed by the craftsmanship of the puppets, and their eloquent movements, especially the puppet Kiyohime, a maiden who becomes a monster when her love

for Anshin, a Buddhist monk, is rejected. I decided to do some "transforming puppets" of my own and subsequently built the Goddesses of Earth and Heaven. Her two faces, upper torso, and double-ended (20 toes) feet are Celastic, hands are wood; hands of the cruel Goddess are articulated wood; costumes are mixed media. Completed 1985-87. Collection, the artists. Photos and drawings, Ellen Rixford.

Central shaft, a wood dowel rod, is the mount for both faces, which are hollow masks. Wood blocks at top of head and ears are mounts for wig and sculpted ears.

A slotted wooden disk holds flat wooden triggers. These are tied to the strings which manipulate the features — eyes, mouth, and spliting of the face in the cruel side.

A   **B**   **C**   **D**   **E**

A and **B**: Frontal and profile views of the Goddess of Earth's "faces" (kind face at left; cruel face and skull at right) and the control rod and handle. These show how the faces are attached to the central shaft, and how the strings to the linkages within the faces are manipulated by the control triggers. **C**: front view of the kind face, showing the eyes pivoted on a horizontal rod passing through the eyeballs. Strings attached to the control trigger make the eyes blink or close. Return springs bring them back to straight-ahead position. **D**, frontal section and **E**, view from below, shows the mechanism of the cruel face's mask. The two halves of the mask, pivoted on a vertical rod, are held closed by four diagonal springs. Pulling the strings tied to the sides of the mask opens it, revealing the grinning skull beneath. The four return springs close the mask again.

Goddess of Heaven, double-faced and double-masked Bunraku-style puppet by Ellen Rixford. In designing her, I considered the iconography: images of sky gods and goddesses in various cultures. Because the sky is full of light, and changes colors, I designed the inner kind face to be translucent, with a light assembly behind it which would change colors via a rotating control. The outer kind face is a fairly standard sculpture, but with
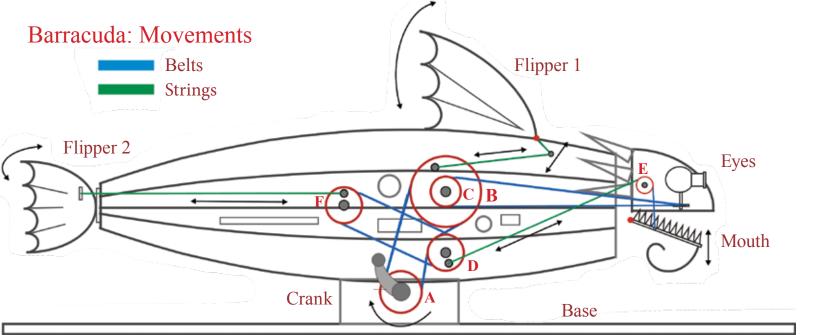
blue-green glass cabochon "jewels" set in the eyes, which catch the light in an arresting and somewhat eerie manner. The cruel face is the same form as the kind face mask, but painted silver, with very richly hued features and open eyeholes which allow the light from the light assembly within to show. The bird mask is similarly painted silver, with the same kind of paint job accenting the features, and similarly open eye holes.

Profile view of the head assembly, showing the masks, which, in this drawing, are slightly positioned away from the inner faces for clarity. In reality, the masks are placed right up against the inner faces, held in place with strong magnets. As the colors of the color cylinder **Cc** are rotated by the control wheel **W**, the colored light shines out from the translucent face, **Tf**, and through the eyeholes of the cruel inner face **Cif**, and the cruel mask **Cm**.

Barracuda, by Pablo Lavezzari: Ferocious fish has moving eyes, a toothy smile in a mouth that opens and closes, "hair" that rises and lies flat by turns, and moveable fin and back flipper. A hand crank powers the movements. 110 cm long. Wood, copper, bronze, glass. 2004. Private collection. Photo, Fernando Velez. Drawing, the artist.

Barracuda: Movements

Belts
Strings

Flipper 1

Flipper 2

Eyes

Mouth

E

F   C   B

D

Crank   A   Base

Peter Markey's masterpiece — Big Wave Machine: Painted wood, 50 cm. tall, 1980. Client, Cabaret Mechanical Theatre, photo by Heini Schneebeli. Waves move vertically, driven by the central camshaft via horizontal followers (unpainted in the picture). The sailors are driven by a crank visible on the right in the photograph. Now motorized, it was originally hand cranked by turning the central crankpin seen on the drawing. This pin drives the two shafts on either side through connecting rods in the shape of a shallow V. See more on multiple cranks and crankshafts in following pages. Directly below is a sketch of one of the more common ones Markey uses in many of his automata. Crank a is the main crank, Crank b is the secondary crank, ab is the link between them. Slightly offsetting the relationship between the 2 cranks assures smooth operation.
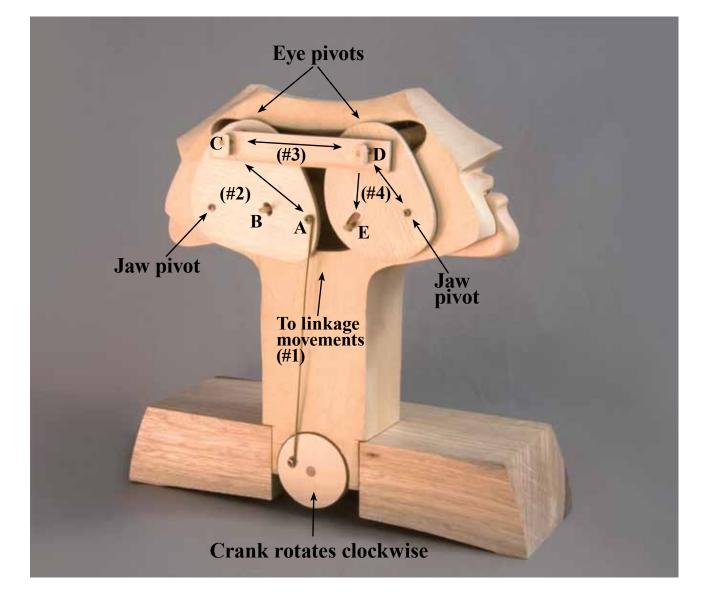
These drawings show Markey's trademark staggered cam lineup, and the multiple cranks he often uses. Below, cams and followers create waves. At right, drawing for Big Wave Machine, above, how the oarsmen work.

Jan Zalud's Your Turn, dialogue of twin faces.

Eye pivots

C (#3) D

(#2) (#4)

B A E

Jaw pivot

Jaw pivot

To linkage movements (#1)

Crank rotates clockwise
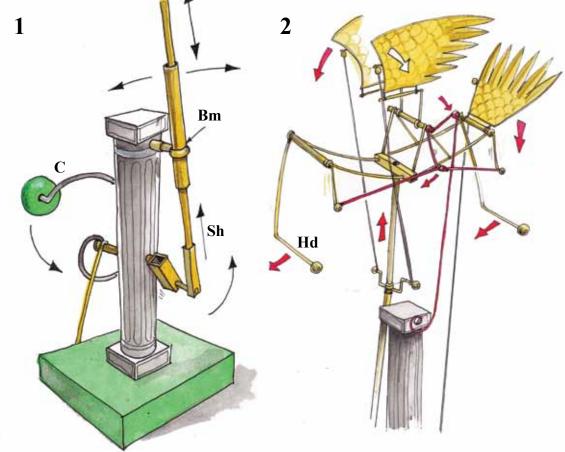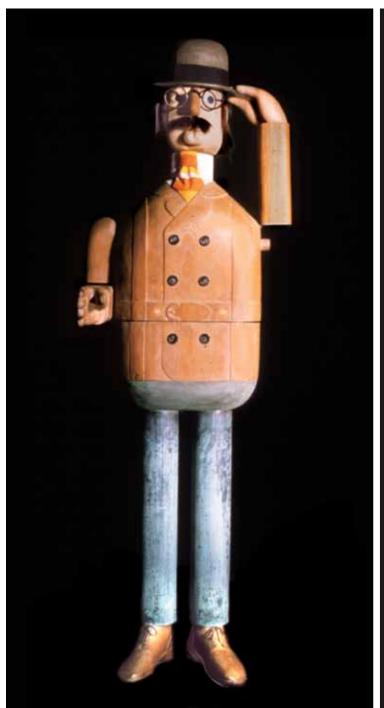
Your Turn: The two faces alternately "speak" as if having a conversation, moving their eyes and mouths, hence the title. The sculpture is approximately 30 cm tall. The head is carved in lime-wood (bass-wood), the base is zebra-wood. Done in 2006. Collection, the artist. Photos, the artist. The crank at the bottom rotates clockwise, pushing the linkage rod **#1**, alternately up and down. As its attachment point **A** pushes up and down, the linkage piece **#2** rocks back and forth, raising and lowering peg **B**, which is attached to the back of the jaw of the face on the left side (in this view from the automaton's back). The jaw rotates around the jaw pivot, opening and closing the jaw. This linkage also causes the bar shaped piece **#3**, to slide back and forth, causing the eyes, attached at **C** and **D**, to move back and forth as well. **#3** also pushes against linkage piece **#4**, and, as **#4** alternately rocks back and forth, it pulls up and pushes down on **E**, which is attached to the back of the jaw on the right-hand face, opening and closing its mouth.
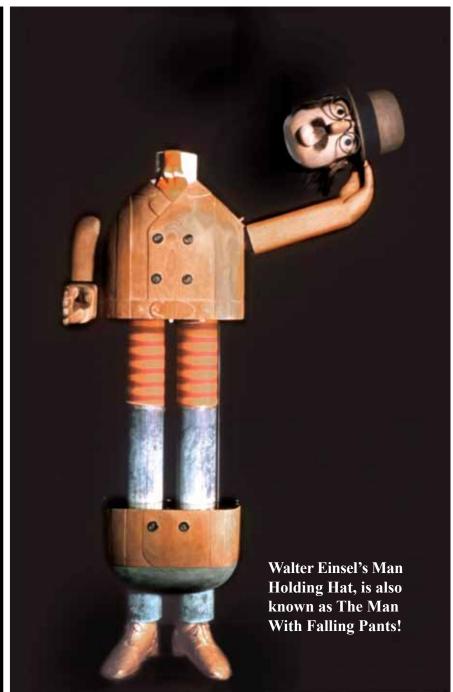
Icarus Flies Undone: by Keith Newstead — the Greek myth of the daring, unfortunate aeronaut who defies the god Apollo, builds himself a set of wings, and attempts to fly across the sky. In the real story, his wings, made of beeswax and feathers, melt and he falls into the sea. Here, far less disastrous but still very embarrassing, he discovers that his underpants have come undone at the front! 12" x 9" x 5". Brass and wood. 2001. Collection of Michael Croft. Photos by Michael Croft, technical drawings of the automaton by the artist.

The mechanism is based on a crank slider. Drawing **1** (with the stand in green) shows the back of the base and the bottom of the crank slider, attached to an offset rod which passes, at a 90° angle, through the base pillar to the crank handle **C**. The primary shaft **Sh** passes through a piece of brass tube (a bearing mount **Bm**) attached to the pillar. This mount can pivot to allow the crank slider to rock back and forth. Drawing **2** shows the "bird cage" from the front. The shaft moves up/down and in a gentle rotary motion, following the motion of the hand crank, and providing the primary movement. Because the wings are fixed to the shaft housing, they are made to "flap" because of the motion of the crank slider. The internal rods, colored red in this drawing, work as a single unit, rotating at the joints. A longer rod **Rd** is fixed to the base, so that, like the wings, other parts must move to compensate for the action of the crank slider shaft. The Icarus figure's feet **Ft** are attached to the back crossbar; his hands **Hd** are attached to the front one. A tether attaches to the tail "feathers" and waves them up and down As the crank slider shaft follows the motion of the crank handle, Icarus' hands and feet alternately pull and push, as if he is "working" the wings.

43

Walter Einsel's Man Holding Hat, is also known as The Man With Falling Pants!
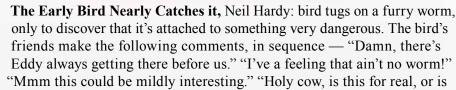
Man Holding Hat: This life-sized gentleman offers the viewer his right hand to shake. When the hand is shaken, his left hand doffs his hat, (with his head still attached to it) and his pants fall down with a loud crash, revealing his colorful striped shorts. Polychromed wood, copper, steel mechanical parts, wire cables, lead counterweights. 1960's. Collection, the artist. Photo, the artist. Drawing: Ellen Rixford. When his right hand **A** is pushed down, lever **a** releases the catch holding his head onto his neck. The weight of his left arm **B**, holding hat and head, causes it to swing down, pushing in lever **b**, and swinging in a pivoted lever with catch **b′**, which holds up his pants. The pants, released from the catch, fall down. Cables and pulleys **c** and **c**, and counterweights **d** and **d** allow the pants to be raised again. The left arm (and head) can now be replaced, the catch holding things together.
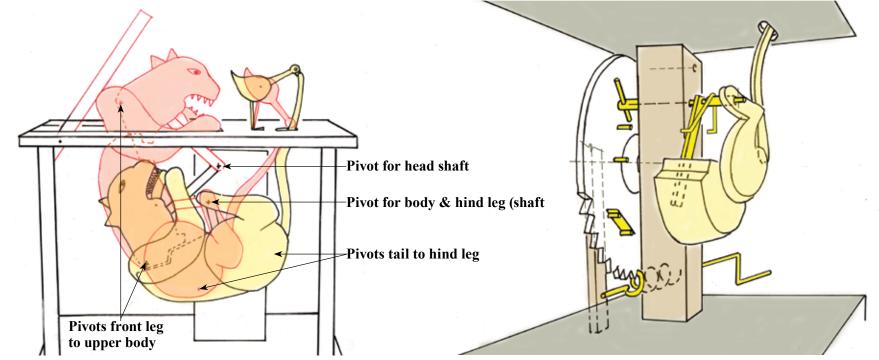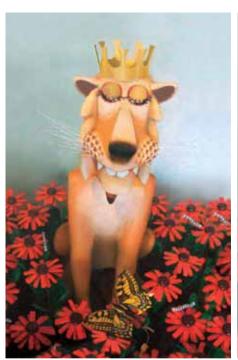
The Early Bird Nearly Catches it, Neil Hardy: bird tugs on a furry worm, only to discover that it's attached to something very dangerous. The bird's friends make the following comments, in sequence — "Damn, there's Eddy always getting there before us." "I've a feeling that ain't no worm!" "Mmm this could be mildly interesting." "Holy cow, is this for real, or is it one of those new-fangled automata?" Dimensions 7" by 7" by 5". Wood painted in acrylics, doors painted to look like subterranean soil layers, complete with bones; brass machine parts. 1994. Piece done in multiples for sale to multiple collectors. These photos taken by one collector, Michael Croft. All photos of the mechanism and all explanatory drawings by the artist.

Pivot for head shaft

Pivot for body & hind leg (shaft

Pivots tail to hind leg

Pivots front leg
to upper body

47
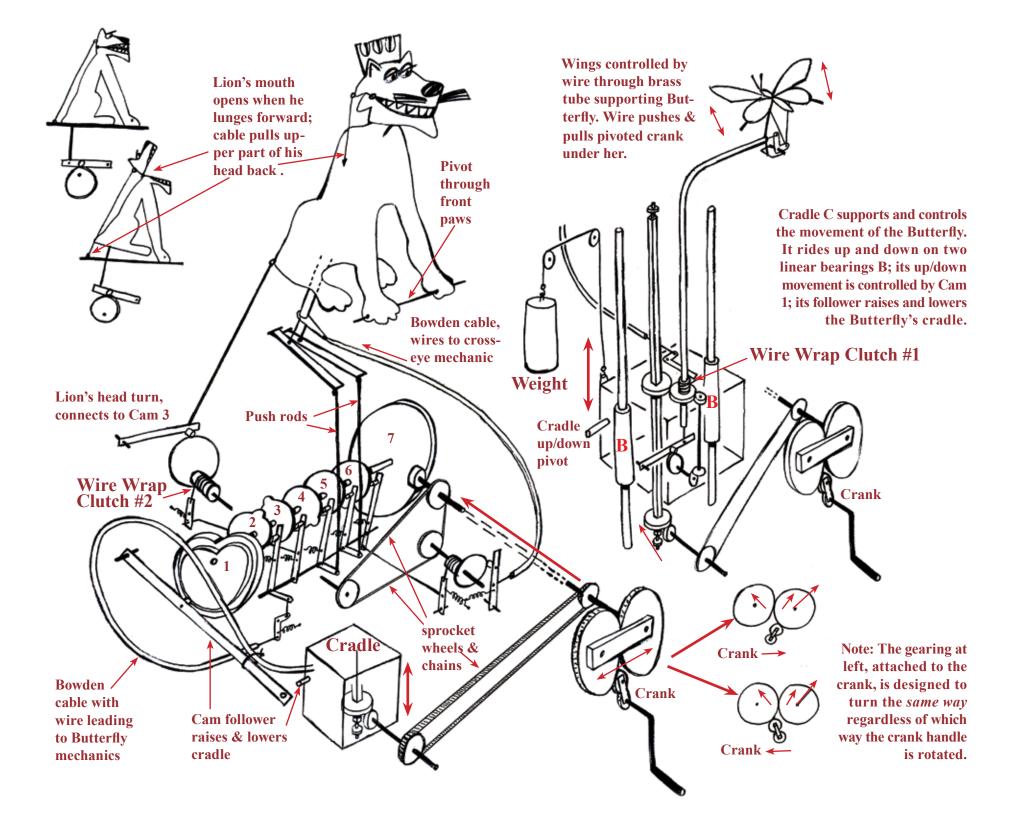
Lion Lepidoptera, by Ron Fuller. The sequence of events: The Lion King snoozes amidst a garden patch of marigolds. The Butterfly is settled on one of the flowers. She takes wing, circles, and flies up to the Lion, fluttering closer and closer. The Lion turns his head to watch her, stares, goes cross-eyed staring at her, and irratably snaps at her twice. Then he gives up. The Butterfly, having escaped, circles, and flutters back down on the marigolds, where she descends once more. The Lion goes back to semi-somnolence. The six photos at left show, in sequence, the unfolding drama between the large sleepy mammal and and the agile — and cheeky — insect.

Lion's mouth opens when he lunges forward; cable pulls upper part of his head back .

Pivot through front paws

Wings controlled by wire through brass tube supporting Butterfly. Wire pushes & pulls pivoted crank under her.

Cradle C supports and controls the movement of the Butterfly. It rides up and down on two linear bearings B; its up/down movement is controlled by Cam 1; its follower raises and lowers the Butterfly's cradle.

Bowden cable, wires to cross-eye mechanic

Lion's head turn, connects to Cam 3

Push rods

Weight

Cradle up/down pivot

Wire Wrap Clutch #1

Wire Wrap Clutch #2

Crank

Cradle

sprocket wheels & chains

Crank

Crank

Bowden cable with wire leading to Butterfly mechanics

Cam follower raises & lowers cradle

Crank

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"When I was a kid growing up in rural Connecticut I was into weird plants and fell in love with a kind of wild orchid that grew in the woods around our house. Its scientific name is Cypripedium Acaule, or pink lady's slipper. I loved it because it was beautiful, but that wasn't all. When not in bloom it's a very unassuming plant, but in spring it puts forth a single blossom that is (like many orchids) a miracle of engineering and loveliness mixed with a manipulative agenda of deceptive bug psychology. In shape and redolence it advertises a reward of nectar, beckoning a bug to come a little closer… closer… and then —oops!— the bug falls into the "slipper" from which there is only one way out — through a narrow passage that forces the bug to pick up pollen on its back or deposit the pollen from its last similarly frustrating encounter. This way, the flower need not spend precious resources on making nectar. I felt sorry for the bugs, but I also wondered what it felt like to be the orchid, sitting there waiting around for something to happen.

"Later, as I set out to make a mechanical impression of the flower, the idea of a beautiful creation sitting on the forest floor struck me as a metaphor for art more generally. I imagined a bronze orchid on a pedestal; what a dull existence it must lead in a gallery, with art lovers like bugs hovering around it, debating its inherent value! It was this dynamic I wanted to suggest by having it occasionally release a deep, resonant sigh.

"I had to make the flower mechanism first because I needed it finished in order to figure out the next steps. I started by carving the flower parts out of jewelers' wax, which I knew could then be cast in bronze or brass or silver. I chose brass because it machines well; I wanted to drill some holes in the pieces after they were cast. The wax itself had enough strength so that I could mock up the mechanism pretty well in it, using stainless steel rods (I use welding rod) as pins for joints. When I disassembled the wax model I plugged the pinholes, leaving just little divots to mark where I would drill the holes in the brass casts. Then I sent them off to a jewelry caster. He had asked me if I wanted to make silicone molds for making extra waxes in case there was a bad casting, or in case I wanted more pieces. I was poor, so I decided to skip the silicone molds and take a chance. In retrospect, that was really dumb. It's always a good idea to have extras; something always goes wrong — as was the case here. The two main lateral petals I had carved out of a different kind of wax (probably cheaper!) and their castings failed. So I ended up fabricating those pieces out of brass strip, wire, and rod — soldered, forged and carved — to get them to more or less match the originals.

"The facing page shows the parts of the orchid sculpture, how they relate to each other, and how they move to open and close the flower."
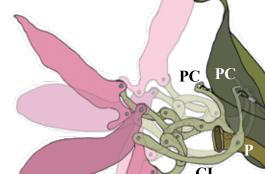
50

Sigh, bronze orchid with the soul of a prima donna, created by Chris Fitch
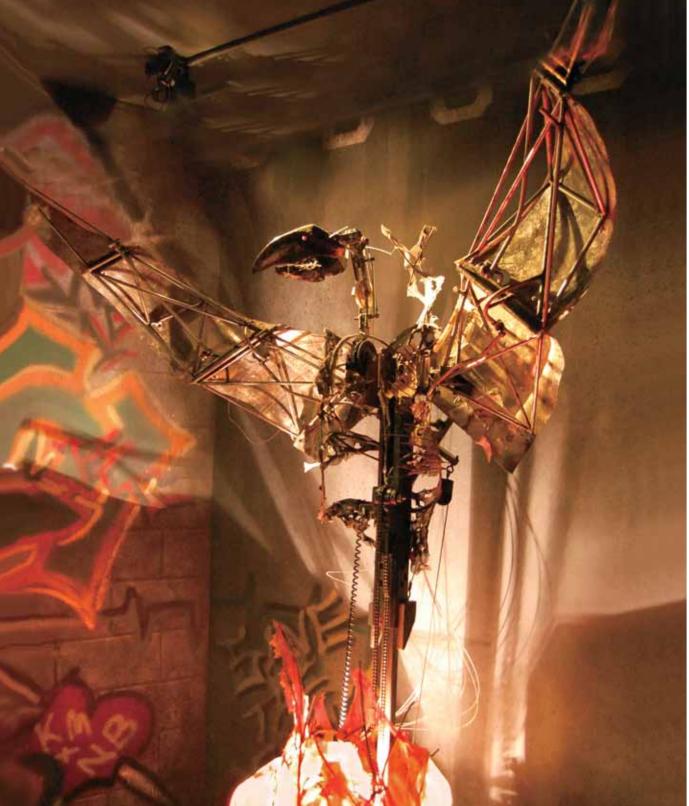
Flower up

Flower Front: As the flower rises and falls, a series of hinges and joints act to open and close the petals. Hinges **H**, universal joints **U** and ball joints **B** alternately pull the side petals in, and articulate them. Pivots **P** allow the top and bottom petals to open and close as the compound levers change the position of the flower's various parts. Springs **S** on either side of the large central petal help the flower to return to a drooped position. The parts were originally carved in wax and then cast in brass.

Flower profiles: Pull cables **PC** emerging from smaller tubes, pulled by the crankshaft inside the pot, lift the flower up, creating a stretching and shrugging gesture that suggests a sigh. When crankshaft allows the cables to slacken, the flower droops, pulled down by its own weight plus a spring return amongst the flower parts. The flower pivots on an attachment point **P** on the larger tube; the "breath" for the sigh comes out of the opening of the larger tube—airflow generated by the bellows and motor within the pedestal. Compound levers **CL** pivot on the larger "breath" tube, pulled by the cables, driving the motion of the flower petals. Most of the flower parts are of cast brass, pivoted on small (¹⁄₁₆th to ³⁄₃₂nd) stainless steel axles with retention rings.
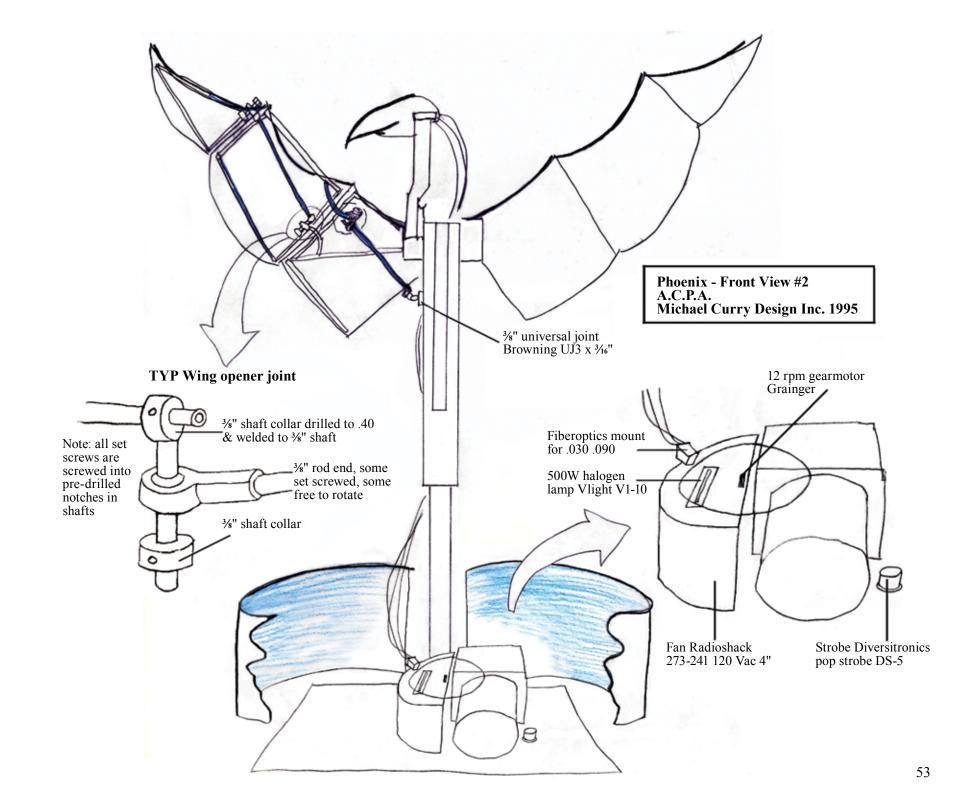
Flower down
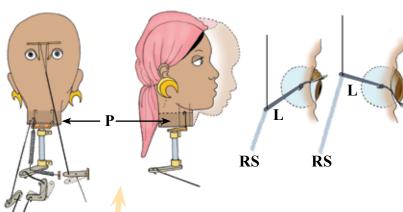
Trash Phoenix: Giant bird emerges from a trash can, by Michael Curry. Above: the trash can closed. Left: Phoenix fully opens. Facing page: drawing showing the trash can opening into the Phoenix; the technical diagram shows specifications for the sculpture. For the very technically minded among you, diagrams of motor interface and time control are on the book website. Size of puppet: 9′ tall. Materials: metal parts, fiberglass, electronic parts. Client, Center for Puppetry Arts. All photos, Melissa McCarriagher. Drawings and diagrams, the artist.

Phoenix - Front View #2
A.C.P.A.
Michael Curry Design Inc. 1995

⅜" universal joint
Browning UJ3 x ³⁄₁₆"

TYP Wing opener joint

Note: all set screws are screwed into pre-drilled notches in shafts

⅜" shaft collar drilled to .40 & welded to ⅜" shaft

⅜" rod end, some set screwed, some free to rotate

⅜" shaft collar

12 rpm gearmotor Grainger

Fiberoptics mount for .030 .090

500W halogen lamp Vlight V1-10

Fan Radioshack 273-241 120 Vac 4"

Strobe Diversitronics pop strobe DS-5

At left, the mechanisms controlling the movements of the Flower Seller's head and face. The base of the neck is a wooden "plug" **P** attached to a metal mounting piece at the end of a steel shaft. The neck plug can be tipped forward, nodding the head; the shaft can be turned, turning the head. Her eyes are on pivots mounted at either side of her glass eyeballs, and levers **L** attached to cables going up to the top of her head and then pulled downward blink her eyes. Return springs **RS** pull the eyes forward again.

Please note: in this drawing, in order to show the mechanics clearly relative to each other, the automaton is seen from the ***back***, rather than the front..
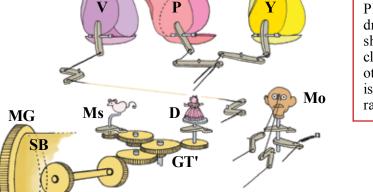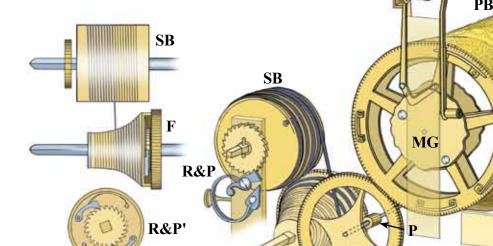
At right, the mechanisms for the movements of the surprises within the flowers (**V**iolet, **P**ink, **Y**ellow) which, unlike the illustration on the facing page, actually open in turn, one after another. The main gear **MG** at the end of the spring barrel **SB** meshes at a 90º angle with a gear whose shaft leads to another gear again meshing at a 90º angle with a small gear train **GT'**. This gear train of spur gears and pinions decreases the torque, but increases the spin speed of the mounts for the doll **D** and the mouse, **Ms** so that they rotate many times faster than the main gear does. The monkey's **Mo** head movements are controlled by the followers (on **S2**) for the cams mounted on shaft **S3**.

This exploded drawing shows the interconnection of all the mechanisms of this piece. More detailed closeups on following pages.

At lower left is the music box, **MBx** a fairly standard model, consisting of a gear driving the pinned barrel which plays the "comb". The musical movement's gear is driven by the main gear **MG** at the end of the spring barrel **SB** (partially sketched in here at the left). Center of the drawing, the spring barrel, with its main gear at the left end, the windup rod **W** and key sticking out at the right end, and the four-gear train **GT** driven by it. The spring barrel has three built-in "ribs" distributed on its surface, which act like cams, to open and close the flowers. The gears in the gear train drive the cams powering the movements of the "surprises" within the flowers, and also power the head and neck movements of the Flower Seller. The shafts holding the followers for the various cams are labeled **S1, S2, S3, S4.** The last gears of the gear train drive the worm gear (endless screw) shaft ending with the governor vanes **G** which keep the automaton running at an even, slow pace. A brake rod **B** at lower right, pushed inward will suddenly halt the governor — and with it, the entire movement.

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La Joueuse de Tympanon, the Hammer Dulcimer Player, by Peter Kintzing and David Roentgen: this elegant automaton, thought to be a portrait of Queen Marie Antoinette, plays eight different classical pieces, with charm and verve, on a kind of dulcimer in the shape of a small harpsichord. Holding a small metal hammer in each hand, she strikes the chords with precision and skill. As she plays, her head nods and turns. Her eyes turn also, but with a slight delay. The figure is about 30 cm tall, the whole piece is about 107 cm in length. Her body, face and arms are made of painted wood; her wig is of real hair; her costume is of embroidered silk with lace and ribbons. The mechanism is of brass and mild steel. The tympanum is of wood, with gilded decorations. Date of completion 1770's to 1780's, though a more precise date might be 1784. This automaton is presently in the collection of the Musée des Arts et Métiers, Paris, France. Photos of the automaton ©Musée des arts et métiers-Cnam, Paris, photos P. Faligot. Photos of the mechanical movements were done by Jean-Luc Chazoule. All technical drawings in this chapter were done by Ellen Rixford.

Below: schematic of the spring barrel, **SB** with its relationship to the fusée **F**. A curled spring-pawl clicks around the ratchet of the spring barrel **R&P**. The second ratchet and pawl **R&P'** in the assembly, within the wide end of the fusée, (bottom diagram at left) has a pair of click-pawls whose little springs press them against the ratchet. The fusée's gear drives a pinion, its large gear drives the main gear **MG** on the same arbor as the program barrel, containing the "information cams" for the music.

The main gear drives a gear train ending in the governor assembly. The governor vanes **G** can be adjusted to control wind resistance. Turning them at 180° or directly facing wind-flow slows the machine down. Turning them at 90° or edgewise to wind flow speeds it up. The assembly can be blocked by the single-notched "deadman's wheel **DW** on the same shaft as the crown wheel **CW** connected to the machine's gear train. At the end of each rotation, an arm connected to the rest of the machine's mechanism clicks into this notch, bringing its L-shaped end **L** into contact with the double "stop dogs" **S** on the governor shaft, stopping the vanes from spinning.

The followers for both the up-down and side-to-side movement of her arms remain in the same position throughout each performance; it is the barrel — with its pinning and cam tracks — which moves. At the end of each tune the automaton stops automatically. It is only in this position that the central cam readers and pin-followers find themselves clear of both pinning and cams. This will allow the program barrel to shift laterally for tune changes. It is also the only position in which the mechanism disengages a tune change cam **TchC** locking device, allowing the operator to freely rotate the tune change cam, selecting which melody is preferred. (See following pages.)
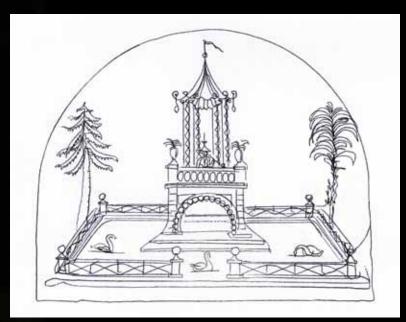
Adjoining the main gear at its right is a gear train leading to the governor assembly **G**. The gear to the right of the main gear drives a steel pinion **P** on the same shaft as a crown wheel **CW** (gear). This crown wheel drives another pinion at the top of the shaft leading to the fan blades of the governor. Just behind the crown wheel (gear) is a wheel with one notch cut into it — a

"deadman's wheel" **DW**. The purpose of this wheel, and the parts adjoining it, is to make sure that the barrel's rotation is fully stopped when the barrel is changing position. This notch is located next to a short steel arm which has an L-bend at the end of it **L**. When, at the end of a tune, the arm's end slips into the notch in this wheel, it brings the L-bend of this arm into contact with a pair of "stop dogs" **S** at the top of the governor shaft. When it is blocked by the L-bend's tip, it will stop the rotation of the governor, bringing the mechanism to a dead stop. Then the barrel is free to slide over and change position for a new piece to begin. Once the barrel is in its new position, the mechanism can be restarted, and Marie Antoinette can continue her performance.
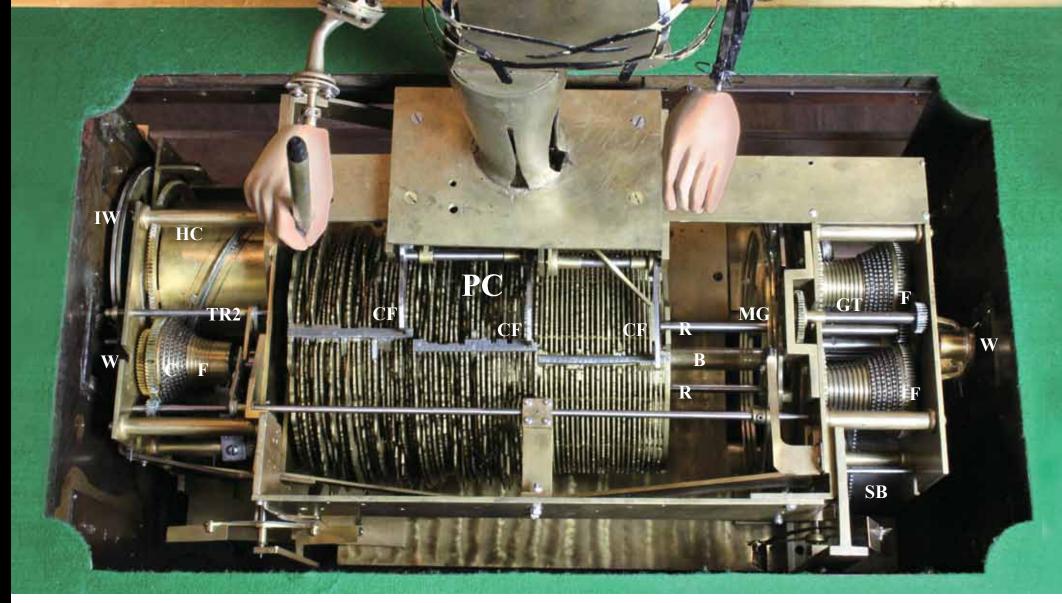
Above, Automaton's drawing of a Chinese temple. Below, a poem translated as: "Child beloved of the ladies, I am everywhere favored by women — and their husbands too!" The poem is signed: "done by the Automaton of Maillardet."

Above is an overhead photo of the mechanism contained within the case on which the doll (photo of doll and case at left) is placed. In succeeding pages, the parts of this machine, and their interaction, will be shown and explained in more photos and several drawings. Following are listed the major components visible in this photo. Additional components, not easily visible here, will be covered in the following pages, which describe the operation of the automaton in detail.

W are windup shafts which, through **F** fusées, and **C**, their chains, wind up the three independent clockwork motors powering the machine—two on the right, powering the rotation of the cam bank, one on the left, powering its lateral

movement left to right. The mainsprings are contained by **SB** the spring barrels, tucked below the fusées, and largely hidden by them. **GT** is the gear train which connects the fusées on the right side, (gear trains on the left side aren't visible in this photo) to **MG** the main gear which, using two projecting rods **R** turns **PC** the program cams, on the main bearing **B** supporting the program cam bank. The program cams' edges, or profiles, as they turn under the cam followers **CF**, govern the movements of the doll's right hand as he draws and writes. The cam followers connect to **RF**, rod followers which operate **LR** linkage rods connecting to linkages **L** in the doll's body, controlling the movements of the hands and head.

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Chapter 8
Magical and Mechanical Evidence: The Late-Renaissance Automata of Francesco I de' Medici

Lily Filson

Abstract In the realization of moving automata for Francesco I de' Medici's sixteenth-century Villa Pratolino outside of Florence, the memory of antiquity informed both the practical and theoretical operations of these "living statues." The 1587 description of the villa and its wonders, *Delle Maravigliose Opere di Pratolino, & d'Amore* by Francesco de' Vieri, associates magical traditions of statue animation with Renaissance automata in a passage that cites Aristotle's description, rooted in atomism and sympathetic magic, of the physical process by which Daedalus animated his legendary wooden Venus. From the fifteenth century onwards, the rediscovery and popularity of Neoplatonic and Hermetic philosophical texts in the Renaissance perpetuated Greco-Egyptian methods of investing man-made vessels, typically cult statues, with some kind of "life" from received celestial influences, thus manufacturing the "living gods" of antiquity. Simultaneously, mechanical texts which preserved mechanical devices and principles from ancient Alexandria were being assimilated to the engineering repertoire of Western Europe, and air and water were harnessed to impart movement to the early modern automata which graced Italian Renaissance hydraulic villas and gardens. For the court of Francesco I de' Medici, the division between our modern scientific concept of air and a metaphysical "spirit" was not yet drawn, and manipulating this occult "influence" was invested with a mastery of a far broader, unseen sphere. For the court philosopher De' Vieri, Neoplatonic and Hermetic writings furnished alternative and not necessarily contradictory understandings of various hidden forces which could cause statues to move. In the late sixteenth century, a much broader conception of "nature" allowed for the confirmation of invisible or "occult" phenomena which did not preclude the magical philosophy of antiquity from being related to the empirical discoveries being made via the production of new mechanical devices. De' Vieri's 1587 panegyric to Pratolino demonstrates that the mastery of mechanical as well as esoteric magical philosophy came to feature in the propaganda of the newly-invested Medici Grand Duke.

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8.1   Introduction

To our modern sensibilities, mechanical physics seems a world apart from magical philosophy, yet an episode in the history of art and technology illustrates their intersection in the early modern period. In the twilight of the sixteenth century, the magical worldview of the Renaissance overlapped with the rediscovery of mechanical texts from antiquity, such as the *Pneumatica* of Hero of Alexandria, producing a rare combination of sculpture, mechanics, and magical philosophy in the material culture of the court of Francesco I de' Medici (1541–1587). Moving statues that seemed alive revived both mechanics from antiquity as well as alluded to philosophy found in texts of Hermetic and Neoplatonic philosophy familiar to Florentine humanists of the fifteenth century. These classical texts offered two ways to bring statues "to life": whereas one relied on insights into mechanical physics with devices that manipulated air, water, heat, and other natural forces, the other turned to capturing astral influences, equally natural in the eyes of the Renaissance, that invested man-made vessels with celestial spirit. In late sixteenth-century Florence, antique legends of living statues fed both the imagination and inspired the production of man-made "gods" to rival the ancient temples of Egypt and Greece, where magical philosophy had overlapped with mechanical technology from at least the Hellenistic era onwards. Francesco I and his circle's interest in the magical ideas of antiquity is documented by the court chronicler Francesco de' Vieri (1524–1591)'s description of moving statues at the Medici Villa Pratolino.[1]

In the last quarter of the Cinquecento, Francesco I commissioned the construction of Pratolino, a lavish suburban villa and gardens a mere five kilometers to the north of Florence; this construction belongs within the larger context of Francesco I's patronage, which saw the expansion of Medici holdings to include the villas of Magia, Lapeggi, Marignolle, as well as his personal Studiolo within the Palazzo Vecchio and Fonderia at the Casino of San Marco.[2] At Pratolino, what had formerly been a tract of farmland owned first by the Orlandini, then until 1568 by a superintendent of works for the Medici, Benedetto di Buonaccorso Uguccioni, was transformed from a "desolate hillside… [that] housed no ghosts of former Medici" into vast water-gardens dotted with fantastic displays of art and technology realized by large teams of artists and engineers under the general direction of the architect and polymath Bernardo Buontalenti (1531–1608).[3]

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[1] Jessica Wolfe, *Humanism, Machinery, and Renaissance Literature* (Cambridge: Cambridge University Press, 2004), 239.

[2] Daniela Mignani, *The Medicean Villas by Giusto Utens*, trans. Stephanie Johnson (Florence: Arnaud, 1995), 15.

[3] Filippo Baldinucci, *Notizie de' professori del disegno da Cimabue in qua* (Firenze: Per Santi Franchi, 1728), 496–497; Clare Brown, *Pratolino and the Transforming Influence of Natural Philosophy* (MA Thesis. Birkbeck College, 2005), 6; Jocelyn Godwin, *The Pagan Dream of the Renaissance* (London: Thames and Hudson, 2002), 175. Other contributing artists include Giambologna, Bonaventura da Orvieto (or da Bagnoregio), Gocerano da Parma, Tommaso Francini, and Maestro Lazzaro delle Fontane; Luigi Zangheri, "Lo splendore di Pratolino e di Francesco I de' Medici," in *Il Giardino d'Europa: Pratolino come modello nella cultura europea*, ed. Centro Mostre di Firenze, 15–18 (Firenze: Mazzotta, 1986).
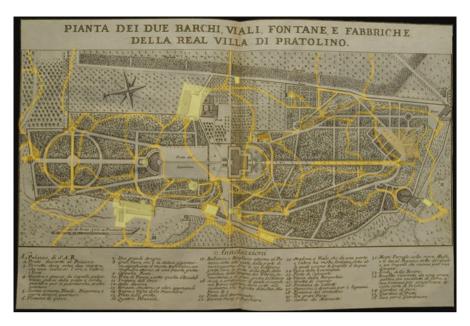
The automata and "wonders" of Pratolino belong to a much larger oeuvre of works spanning the visual arts, architecture, theatre, pageantry, and diverse engineering projects; the automata were only a drop in the proverbial bucket, and certainly not the only works to acquire a "magical" renown. Others included a perpetual motion machine, a device that could create animated, colored images using only water and iron filaments, and artificial clouds deployed during one memorable *intermezzo* performed in the theater of Pratolino's villa.[4] There are accounts of apparently demonic rituals performed as entertainment for the Grand Duke and Bianca Capello, accompanied by pyrotechnics, chemical reactions, and other sophisticated special effects.[5] Francesco I himself is often painted in studies as an introverted recluse, obsessive in his love of alchemy, experiments, and esoteric philosophy. In possession of vast resources and riches and the heir to the fertile centuries in Florence which saw the revival of Neoplatonic philosophy, no other time, place, or court was as ripe as Francesco I's to put into practice both the magical and mechanical theories recovered from antiquity. The Pratolino automata were just one aspect of the spectacular, seemingly divine powers put on exhibition by this ruler to his courtly guests.

At Francesco I's Pratolino, animated statues numbered in the dozens, arranged in choreographed theatrical tableaux in the numerous grottoes throughout the villa and park. They depicted shepherds, gods, nymphs, tritons, satyrs, animals, and even autonomous musical instruments. We have a reasonable idea of their hydraulic power source from the locations of the principal canals and pipes in later plans of Pratolino, as well as from the study of Pratolino's devices by other engineers who included similar models in their writings. Salomon de Caus' *Les raisons des forces mouvants* (1624), for example, featured a grotto that reveals its operative mechanism and whose Galatea automaton has been compared to Pratolino's original. Deduction from what was known from Greek texts like Hero of Alexandria's *Pneumatica,* recently translated from the Greek into Latin in 1575 and the vernacular in 1589, as well as notes taken by Pratolino's visitors through the centuries, help to further bring the villa to light (Figs. 8.1 and 8.2).[6]

[4] Luciano Berti, *Il Principe dello Studiolo: Francesco I dei Medici e la fine del Rinascimento fiorentino* (Firenze: Maschietto & Musolino, 2002), 93–94; Luigi Zangheri, *Pratolino: il giardino delle meraviglie*, 2 vols (Firenze: Edizioni Gonnelli, 1979), vol. 1, 44; Mila Mastrorocco, *Le Mutazione di Proteo: I Giardini Medicei del Cinquencento* (Firenze: Sansoni, 1981), 119.

[5] Berti, *Il Principe dello Studiolo,* 218–220.

[6] Salamon de Caus, *La raison des forces mouvantes* (Paris, 1624), pl. 32; Zangheri, *Pratolino: il giardino delle meraviglie*, vol. 1, 117. Although Giorgio Valla translated fragments of Hero's work into Latin in 1501, including devices operated by water, air, and steam, the first full translation was not until 1575 with Commandini's *Pneumatica*; Silvio A. Bedini, "The Role of Automata in the History of Technology," *Technology and Culture* 5 (1964): 24–42, at 25; cf. Teun Koetsier, "Simon Stevin and the Rise of Archimedean Mechanics in the Renaissance," in *The Genius of Archimedes: 23 Centuries of Influence in Mathematics, Science, and Engineering*, ed. Stephanos A. Paipetis and Marco Ceccarelli, 85–112 (Dordrecht: Springer, 2010), 87–88, who uses Commandino. Vernacular versions in 1589 (ed. Giovanni Battista Aleotti), 1592, and 1595 (the latter two from Alessandro Giorgi da Urbino). Derek J. DeSolla Price, "Automata and the Origins of Mechanism and Mechanistic Philosophy," *Technology and Culture* 5 (1964): 9–23, at 22. Notable visitors who left

Fig. 8.1 Bernardo Sansone Sgrilli, *Pianta delle due barchi, viali, fontane e fabbriche della real villa di Pratolino*, from *Descrizione della Regia Villa, Fontane, e Fabbriche di Pratolino* (1742), pl. 7
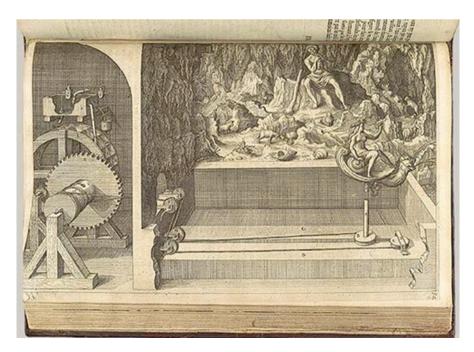

Fig. 8.2 Salomon de Caus, *Grotto of Gal*atea, from *Les Raisons des forces mouvants*, pl. 32

In spite of their virtuosity, the hidden mechanical devices that powered Pratolino's automata were not overtly celebrated in the outpouring of dedicated compositions between the years 1586 and 1587 marking the villa's completion.[7] To this body of works belongs the 1587 *Delle Maravigliose Opere di Pratolino, & d'Amore* by Francesco de' Vieri, also known as Verino Secondo. De' Vieri's descriptions of Pratolino's "occult automata" and their comparison to ancient animated statues form the basis of this study's analysis of the magical identity coded into their contemporary reception. Whereas the later eighteenth-century *Descrizione della Regia Villa, Fontane e Fabbriche di Pratolino* by Bernardo Sansone Sgrilli also employed the term "occult," it was exclusively applied to "hidden" devices and stripped of all inflections of esoteric philosophy, which make De' Vieri's earlier text critical to the present analysis.[8]

In his *Delle Maravigliose Opere di Pratolino,* De' Vieri offered a more reconciliatory account of the occult and magical workings of the automata at Pratolino. To this end, it must be questioned to what extent the reintroduction of classical mechanics in the Renaissance served as evidence against the magical worldview depicted by the automata? As I argue in this chapter, "magical" or, more properly, theurgic texts, based upon ancient Neoplatonic and Hermetic authorities, were often considered significant contributors to the evidence that mechanical principles could cause statues to move. Understanding the mechanical workings of moving statues, such as those at Pratolino, did not prevent people like De' Vieri from accepting the possibility that other unseen forces, increasingly theorized to be of natural rather than demonic agency, might serve similar purposes equally well. Evidence of the invisible was offered abundantly in the writings of Renaissance Platonists, such as Ficino and Agrippa, which allowed for a much more expansive understanding of natural causation. What this suggests is that text continued to serve as a privileged vessel of authoritative truth, which was not replaced by experiential evidence, but rather continued to work in tandem more so than in opposition. Renaissance architects, artists, and inventors developed the skills to build such automata through the knowledge they received from works of classical mechanics, but this did not prevent a considerable number of them from taking seriously the idea that the ancients' methods,

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their accounts include Michel de Montaigne (1533–1592; *Journal de voyage en Italie, par la Suisse et l'Allemagne en 1580 et 1581*, ed. Charles Dédéyan (Paris, 1946), 161–66), Fynes Moryson (1566–1630; *An Itinerary Containing his Ten Yeeres Travell through the Twelve Dominions of Germany, Bohmerland, Sweitzerland, Netherland, Denmark, Poland, Italy, Turky, France, England, Scotland, & Ireland* (Glasgow: James MacLehose & Sons, 1907), vol. 1; Henry Wotton (1568–1639; *The Elements of Architecture* (London: John Bill, 1624); John Evelyn (1620–1706; *The Diary of John Evelyn*, ed. William Bray (New York and London: M. Walter Dunne, 1901), vol. 1. Others left anonymous descriptions: see Anonymous, "Letters of an Artist on Italy, 1798," *Blackwoods Edinburgh Magazine* (1829): 574. From a German architect, see Christian Hülsen, "Ein deustcher Architekt in Florenze (1600)," *Mitteilungen des künsthistorisches Instituts in Florenze* 2 (1912): 152–175.

[7] For further tributes in music and verse, see Webster Smith, "Pratolino," *Journal of the Society of Architectural Historians* 20 (1961): 155–168, at 165f.

[8] Bernardo Sansone Sgrilli, *Descrizione della Regia Villa, Fontane e Fabbriche di Pratolino* (Firenze, 1742).

Fig. 8.3 Lorenzo
Bartolini, *Demidoff
Monument*, Pratolino. 1847

perceived to be rooted in magic, ritual and, in many cases, the astrological tradition,
could "invest" their artworks with some living, animate quality that descended to
visible and invisible rays from stars and planets above. Ultimately, this was sup-
ported by a much broader conception of "nature," in which visible and invisible
forms of evidence did not determine the boundaries between the "magical" and the
empirical (Fig. 8.3).

No physical traces remain of the automata themselves. The villa and most origi-
nal features of its park were demolished in the 1820s. The site where the villa once
stood is today marked by a nineteenth-century monument. We have limited visual
depictions of the automata *in situ* within their original choreographed scenes from
two principal sources: a series of drawings by Giovanni Guerra from c. 1600, which
are presently conserved in Vienna's Albertina Museum, and a series of engravings
by Stefano della Bella that accompanied Sgrilli's *Descrizione*. Nonetheless, the

grottoes and their automata can be read about widely in similar works which appeared in the next century.[9]

Whereas an aura of magic pervades the writings about Pratolino and Francesco I de' Medici, the automata are not often cited specifically and virtually never elaborated upon in conjunction with De' Vieri's description. In 2002, historian Joscelyn Godwin recognized the associations Pratolino's automata would have evoked with Hermetic and Neoplatonic philosophy, primarily the "god-making" passage, which will be explored in further depth below.[10] However, this association is considered in isolation and left unconnected to the description left of the Pratolino automata by its sixteenth-century author. In a similar vein, Mila Mastrorocco in 1981 analyzed the magical identity of Pratolino's automata, pointing to the retention of magical aspects or, perhaps more accurately, to the ambivalence expressed towards what was considered part of the natural world in the age's passion for experimentation. Specifically, the "machine which metamorphosed to human appearance" is used to highlight the Renaissance attitude towards what could be classified as *scientia*, natural philosophy, or magical philosophy.[11] Elsewhere, Mastrorocco argues that the "most intimate significance" of Pratolino is its esotericism and the fact that it functioned as a "dedicated space" to the merging of religious, mystical Neoplatonism and "the magic value attributed to the science of the ancients."[12] Yet, as with Godwin, these impressions and readings into the Hermetic-Neoplatonic keys of Pratolino by Mastrorocco are not read against Francesco de' Vieri's association of Pratolino's automata explicitly with the magically-animated automata of classical antiquity.

In his 1986 essay, Alessandro Vezzosi does connect, if briefly, De' Vieri's text with the theoretical, magical animation of Pratolino's automata.[13] Yet Vezzosi's summary is over-generalized and risks leaving the impression that the Pratolino automata replicated the methods of the ancients. Specifically, that just as the Venus created by Daedalus in antiquity was animated by placing quicksilver mercury in her central cavity, in the same manner was the Pan automata created in the sixteenth century at the Villa Pratolino; likewise, the Pratolino automata of Galatea possessed the same qualities of an engraved, apparently talismanic marble or transparent stone depicting the "Mercury of Pasone." Ultimately, a closer examination of De' Vieri's text demonstrates that Vezzosi's reduction, though certainly provocative, is grossly oversimplified.

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[9] See Luigi Zangheri, "I giardini d'Europa: una mappa della fortuna medicea nel XVI e XVII secolo," in *Il Giardino d'Europa: Pratolino come modello nella cultura europea*, ed. Centro Mostre di Firenze (Firenze: Mazzotta, 1986), 82–92.

[10] Godwin, *The Pagan Dream of the Renaissance*, 174.

[11] Mastrorocco, *Le Mutazioni di Proteo*, 125.

[12] Ibid., 98–99.

[13] Alessandro Vezzosi, "'Pratolino d'Europa,' degli antichi e dei moderni," in *Il Giardino d'Europa: Pratolino come modello nella cultura europea*, ed. Centro Mostre di Firenze, 18–24 (Firenze: Mazzotta, 1986), 24.

8.2 Magical Automata of Antiquity and Pratolino in the Words of Francesco De' Vieri
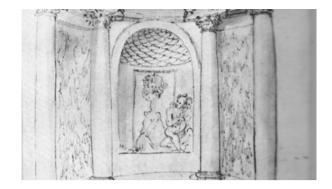
In his description, De' Vieri linked the Pan and Galatea automata of Pratolino to the Venus of Daedalus and the Mercury of Pasone, respectively.[14] Chapter IV opens with a list of objectives that De' Vieri hopes to achieve, third among which is the demonstration that Pratolino's modern works surpass those of antiquity. It is within this relationship to antiquity, one undeniably characteristic for its age, that De' Vieri introduces the two automata from Pratolino.

De' Vieri writes that the statues of Daedalus, as recounted by Aristotle in the first book of *On the Soul*, were as Democritus originally described: the atoms of the soul move themselves first, then the soul, and then the body. How this was affected in the Venus of Daedalus is described by De' Vieri as such: the statue moved because *argente vivo*, "living silver" (a name for the chemical element mercury), moved inside, moving the wooden statue as a living soul animates the body. De' Vieri also cites Plato's *Meno* where it makes mention of the mobile statues of Daedalus. The second antique marvel that De' Vieri introduces is a "Mercury of Pasone," described as a relief joined to and placed inside a certain marble or transparent stone in such a manner that it was not clear whether the Mercury was in its interior or exterior. I venture here by the capitalization of "Mercury" that De' Vieri intends the mythological figure, not the physical substance of the previous example, and hazard a guess that this might have been an inscribed image of the god onto the stone—a talisman, by any other name. De' Vieri also cites Aristotle's *Metaphysics* for its mention of the same.

De' Vieri then proceeds to parallel these ancient works with those of Pratolino. He does not at any point write that a Pratolino automaton replicated the operating principle of the statues of Daedalus described by Aristotle and Democritus. Rather, the sixteenth-century text states that, if the statues of Daedalus were considered miraculous because they moved themselves from place to place, Pratolino's statue of the god Pan is more marvelous because it not only stands up and sits down, but plays music and moves its eyes and head. The Mercury of Pasone, which seemed to appear in relief simultaneously within and outside of its marble or transparent stone, is related to the Galatea automaton, which surpasses this antique model in its motion. De' Vieri describes the starting position of the Galatea within certain rocks, then its foray into the "sea" before it returns again to the rocks. In the preceding chapter, the action of the Galatea's choreographed mechanical scene is revealed: when the rocks have parted, the Galatea appears, riding on top of a golden shell drawn by two dolphins spouting water at the sound of a conch-shell blown by a Triton-automaton. Two attendant nymphs hold branches of coral in their hands which spout water. In this way, claims De' Vieri, the Galatea exceeds the Mercury

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[14] The fourth chapter is entitled: "Comparison of some very artificial works of Pratolino with some of the ancients."

Fig. 8.4 Giovanni Guerra,
*Artificiata ruinata e belo
ingano suona il tritone
Galatea vien fuori*, detail.
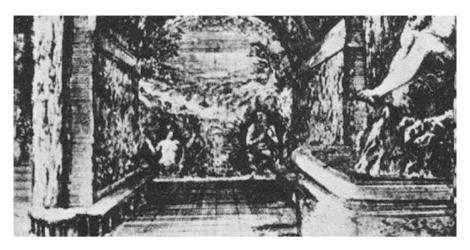Albertina Museum,
Vienna. 1601

Fig. 8.5 Giovanni Guerra, *Pan dio di pastori di cui l'amata sua Siringa in canna...*, detail. Albertina Museum, Vienna. 1601

of Pasone of antiquity because it is simultaneously inside and outside, "quiet and mobile."[15] (See Figs. 8.4, 8.5, 8.6, and 8.7).

Though neither automaton has survived, both are documented to varying degrees of detail either directly or indirectly. Salamon de Caus' grotto-perspective cited above is believed to best preserve the appearance of the Pratolino Galatea, as the original is seen only in a sketchy form in a drawing by Giovanni Guerra. The Pan can be seen in a sketch by Giovanni Guerra and within the architectural context of its eponymous grotto in a Stefano della Bella engraving. The ruins of this grotto can still be found on the original site.

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[15] Francesco de' Vieri, *Delle Maravigliose Opere di Pratolino, & d'Amore* (Firenze: Marescotti, 1587), 54, 56–8, 61–4. My translation.

Fig. 8.6 Giovanni Guerra, *Grotto of Pan*, detail. From Bernardo Sansone Sgrilli, *Descrtizione della Regia Villa, Fontane, e Fabbriche di Pratolino* (1742), pl. 4

Fig. 8.7 Present-day state of the Grotto of Pan, Pratolino. Photo by author (2010)

8.3 Pratolino Automata as Practical Counterpart to Theoretical Renaissance Theurgy

Even though a close examination of De' Vieri's text yields a different impression than Vezzosi's, the comparison of actual late-Renaissance automata with legendary classical models may not be a mere recourse to stock humanistic conventions to glorify a revived antiquity. Rather, I argue that De' Vieri's passages speak to the contemporary fascination with theurgy and magical philosophy, and fill the lacuna as the practical counterpart to the demonstrated evidence of its presence as theory in Renaissance philosophy. Mary Quinlan-McGrath has written most recently about the significance that Ficinian astrological image magic, which essentially reproduces the operational mechanism of Neoplatonic and Hermetic theurgy, held for Renaissance artworks, architecture, urban design, and the organization of life and society; yet automata, the only kind of artwork capable of independent motion (and a convincing semblance of life), are omitted.[16] When the original passage of Aristotle that De' Vieri cites is located, this operating principle emerges, which echoes these magical and natural philosophical currents of thought elsewhere in the Renaissance.

Whereas De' Vieri summarized the operating mechanism of the quicksilver mercury in Daedalus' statue in a linear fashion (the soul moves first the stars, then the body), this particular passage of *De anima* preserves an element of the early atomic theories of Democritus. In this case, a sympathetic relationship is proposed between the "spherical atoms" that make up the soul, how through their ceaseless movement they draw the body in motion with them thus making it move, and how the movement of quicksilver mercury imparted movement to its container—in this case the wooden Venus of antiquity—in an identical and sympathetic process.[17]

Although De' Vieri offers no further particulars about this magical method of statue animation, he implicitly accepts the ancients' god-making capacity in a later chapter: "all of the artifices, and ingenious devices" were indeed used to satisfy, delight, imitate, and to "fake wonderful things; and in this way it is also true that they erred by faking God."[18] Furthermore, De' Vieri asserts that the most awesome works of the ancients were those whose operating principle remains elusive, "either because the principle is unknown, or rather because the operations shall always be occult while we live in this world." In his usage of the word "occult" here, De' Vieri is referring to another kind of hidden operation beyond human understanding, not the simple hidden wheels and canals which are also described as occult in the same work.[19] De' Vieri credits Aristotle with the reduction of natural philosophy to perfection, understanding the "workings of God," which naturally are no longer

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[16] See Mary Quinlan-McGrath, *Influences: Art, Optics, and Astrology in the Renaissance* (Chicago: University of Chicago Press, 2013).

[17] Aristotle, *De anima,* trans. W. S. Hett (London: Loeb Classical Library, 1956), I.3, 406b15-407a2.

[18] De' Vieri, *Delle Maravigliose Opere di Pratolino*, 75.

[19] Ibid., 34, 64, 75.

Fig. 8.8 Giorgio Vasari, *Castration of Ouranos by Saturn*, Palazzo Vecchio, Florence. 1563. Photo by author (2017)

marvelous or stupendous on account of human ignorance, yet he still leaves room for other operations to elude comprehension in the material state, implying another plane of existence even beyond the workings understood to be those of God. Although to most readers, De' Vieri's citation of Aristotle conformed perfectly to Scholastic and post-Tridentine norms and mores, it is also a possibility that he was using Aristotle's authority to allude to a more controversial, yet no less current, theurgic current of thought in Francesco I de' Medici's milieu. It would not be the only instance in the court literature associated with Francesco I that a deeper esoteric meaning lay coded under a thin veneer of Aristotelian natural philosophy. For instance, in a book of instructive conversations with the young prince, Giorgio Vasari describes the rare iconography of the *Castration of Ouranos by Saturn* on the ceiling of the Room of the Elements in the Palazzo Vecchio in terms of the generation of Venus in the sea foam by the falling of heat transformed into matter (Ouranos' testicles), rendered mortal and corrupt. For all of its apparently Aristotelian overtones, Vasari's exegesis of this uncommon theme has also been revealed to have its basis in the ten Sephiroth of the Kabbalah (Fig. 8.8).[20]

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[20] Vasari, *Le Opere con nuove annotazioni e commenti*, vol. 8, 19–20, quoted in Godwin, *The Pagan Dream of the Renaissance*, 77.

Although the Aristotelian/Democritean citation of the operating principles of the Daedalian statues provides a modicum of mechanical or proto-naturalistic rationale for the otherwise supernatural animation of the wooden Venus of antiquity, the motive quality of the quicksilver mercury in its container is essentially positioned as a relationship of magical sympathy to the identical relationship of the soul's atom's movement to the body that contains it. Regardless that this method of animation is not explicitly duplicated in the Pratolino automata, the connection which De' Vieri draws between these legendary animated statues of antiquity and Pratolino's late-Renaissance sculptures links actual, documented works of art and technology with recently recirculating methods of "bringing to life" cult statues from antiquity: either mechanical (hydraulic/pneumatic/clockwork) or magical in the sense of depending on unseen, or occult, sympathetic relationships between the planets, stars, angels, demons, or spirits, and material earthly objects, such as herbs, plants, stones, animals, etc. In this way, De' Vieri reconciles the evidence furnished, on the one hand, by the contemporary automata at Pratolino and, on the other, the evidence on offer in the classical texts. The experiential evidence provided by the mechanical motions of the statues is not used to deny that the ancients were capable of imbuing their statues with a more sophisticated "magic" that is lost to us, but rather to compliment his understanding of the artifice at work at Pratolino. Although he was quick to veil such occult forces under the guise of Aristotelian natural philosophy, De' Vieri nevertheless accepted the ancient texts' assertion that it is possible for invisible forces to be at work, either alone or in tandem, with the visible mechanics on display.

Both traditions, the mechanical and the magical, can be traced separately from their origins in antique Alexandria through the Muslim and Byzantine Eastern lenses to their initial reception in the West during the Middle Ages, and the refinement that the rediscovery of Greek texts brought in the fifteenth century. We will now make a broad sketch of these transmissions, which at times accompanied one another and at other times diverged dramatically to eventually return full-circle, to examine how the Pratolino automata combined both magical and mechanical philosophies culled from Greco-Egyptian antiquity.

8.4 Theurgy in Context: Hermetic, Neoplatonic, and Renaissance Texts and Tradition

A similar philosophy of animating statues to that known to Aristotle is reflected in later Greek philosophy which was widely read in Renaissance Italy. When Greek manuscripts preserving the works of Neoplatonic philosophers and works ascribed to Hermes Trismegistus arrived in fifteenth-century Florence, Marsilio Ficino (1433–1499) was ordered to translate them immediately. Some Hermetic writings had been known to the early Church. From this period through the Renaissance, they were believed to prefigure Christianity, leading problematic passages like the god-making method of the *Asclepius* text to be either overlooked or condemned.

Ficino's translation of the *Corpus Hermeticum*, Neoplatonic philosophers like Proclus and Iamblichus, and the incorporation of their tenets into his original writings popularized these currents of thought and flooded Renaissance culture with what was believed to be wisdom derived from remote Egyptian antiquity.

Furthermore, much of this knowledge was attributed to the mytho-historical figure of Hermes Trismegistus, a sacred composite of the Greek god Hermes, the Egyptian god Thoth and, in some traditions, an antediluvian followed by a Babylonian Hermes. In these accounts, it was the second, originally Babylonian Hermes who was credited with bringing the method of manufacturing living idols to Egypt. Another facet of this tradition is that the third and final Egyptian Hermes also taught Asclepius, the healer of Greek mythology, who brought medicine, star magic, and other wisdom from Egypt to the Greco-Roman world, and within the Hermetic corpus of texts, it is the *Asclepius* which contains instructions to bind spirit to statues, and consequently manufacture the "living idols" of the Egyptian temples. This method relied upon introducing herbs, aromatics, stones, and other natural materials into the body of the statue, creating sympathetic bonds between these materials and celestial spirits, which would in this way be drawn down and contained. A virtually identical process emerged in Neoplatonic theurgy, which wed the techniques of Egyptian magical papyri to Platonic metaphysical philosophy, and which also proved influential to Ficino's writings. Nevertheless, there are more similarities than differences in their respective theurgic philosophies.

Neoplatonic theurgy was a belief system oriented towards the supreme union of the individual human soul with the All. Distinct from earlier conceptions of magic, theurgy "used the procedures of vulgar magic primarily to a religious end."[21] As Wouter Hanegraaff has explained, "theurgy is the work of the gods on man, not the work of man on the gods. Neither the rationale behind its operations nor the meaning of its symbols can be understood by mere humans, nor need they be: what is essential is that the ritual is performed correctly."[22] More generally, the term theurgy has been used to encompass the entirety of the Neoplatonists' "extravagant rituals for invoking the gods and heightening their own magical powers."[23]

Animation through the investment of statues and other man-made vessels with spirit drawn down from the stars was one facet within the late-antique Neoplatonic theurgy which Proclus, Iamblichus, Porphyry, and others distinguished as *Telestikè*. Historians surmise that its principal aim was the practice of consecrating and animating statues. In a story recounted by Proclus (412–485), one Julian the Theurgist, the earliest proponent of the art, is credited with manufacturing from clay a human head which emitted flashes of lightning, sending the Dacian army fleeing and

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[21] E. R. Dodds, *The Greeks and the Irrational* (Berkeley: University of California Press, 1951), 291.

[22] Wouter Hanegraaff, "Sympathy or the Devil: Renaissance Magic and the Ambivalence of Idols," *Esoterica* 2 (1998): 1–44, at 6.

[23] Richard Kieckhefer, *Magic in the Middle Ages* (Cambridge: Cambridge University Press, 1989), 26.

bringing victory to Marcus Aurelius.[24] Theurgy was not extensively defined, however, until Proclus himself. Within his works, more specialized names appear for the various magical operations that today we know simply as "theurgy": τελεστική remained the consecration and animation of statues, and συμβολα were the concealed combinations of materials held to be their animating agents within.[25] Proclus' commentary on the Chaldaean Oracles, which some believe to also have been utterances or writings original to Julian the Theurgist or his father Julian the Chaldaean, survived through an eleventh-century Byzantine commentary by Psellus (1018- c. 1078) and, along with the *De sacrificiis et magia,* became authoritative for later writers on theurgy.[26] The earlier works of Iamblichus (c. 242–327), specifically the treatise *De mysteriis,* sometimes known as the *Theurgia,* assigned theurgy a significant role in Neoplatonism and ushered in a "vogue" for the art.[27] This work's tenet, that stellar manifestations were the true vessels of the gods and that an imitation of their universal forms enabled the theurgist to draw their spirit into earthly vessels, proved a tenacious concept when Neoplatonic treatises were rediscovered in Renaissance Italy.

Although the image of Plotinus (ca. 204–270) as a theurgist himself has been challenged, Plotinist philosophy's tenet that beings on Earth are linked with heavenly bodies through an intricate, living network of influences offered the rationale for how magic and prayer can work through natural sympathetic bonds within the universe.[28] Furthermore, a discussion of invested vessels appears in the fourth *Ennead*, which were collected and edited by Porphyry *(*c. 234-c. 305)*,* and Plotinus is cited in later Renaissance works on the same antique magical technique. Marsilio Ficino's 1489 *De vita coelitus comparanda,* "On Obtaining Life from the Stars," the

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[24] Georg Luck, "Theurgy and Forms of Worship in Neoplatonism," in *Religion, Science, and Magic: In Concert and in Conflict,* ed. Jacob Neusdner et al., 185–228 (Oxford: Oxford University Press, 1989), 186.

[25] Proclus, *Timaeus,* III.6.13, I.273.2, cited in Dodds, *The Greeks and the Irrational,* 292.

[26] For the Chaldaean Oracles as the "basic code of theurgy," see Luck, "Theurgy and Forms of Worship in Neoplatonism," 185ff; Dodds, *The Greeks and the Irrational*, 283; Pierre Boyancé, "Théurgie et télestique néoplatoniciennes," *Revue de l'histoire des religions* 47 (1955): 189–209; Hans Lewy, *Chaldaean Oracles and Theurgy: Mysticism, Magic and Platonism in the Later Roman Empire* [1956] (Paris: Etudes Augustiniennes, 1978), 247–48, 495–96. For Proclus's commentary, see Anne Sheppard, "Proclus's Attitude to Theurgy," *The Classical Quarterly* 32 (1982): 212–224; Laurence J. Rosán, *The Philosophy of Proclus* (New York: Cosmos, 1949); Lewy, *Chaldaean Oracles and Theurgy*, 462–3; Andrew Smith, *Porphyry's Place in the Neoplatonic Tradition* (The Hague, 1974), 111–21; Jean Trouillard, "Le merveilleux dans la vie et la pensée de Proclus," *Rphilos* 163 (1973): 439–451 and *L'un et l'âme selon Proclus* (Paris: Belles lettres, 1972); André-Jean Festugière, "Proclus et la réligion traditionelle," *Mélanges Piganiol* 3 (Paris, 1963): 1581–1590 and "Contemplation philosophique et art theurgique chez Proclus," *Studia di storia religiosa di tarde antichità* (1968): 7–18.

[27] Sheppard, "Proclus's Attitude to Therugy," 212.

[28] Dodds refutes the claim that Plotinus was a theurgist himself and was instead a kind of lone beacon of lucidity before his successors' retrogression to "spineless syncretism" (Dodds, *The Greeks and the Irrational*, 286). Cf. Gregory Shaw. "Theurgy: Rituals of Unification in the Neoplatonism of Iamblichus," *Traditio* 41 (1985): 1–28.

third book of his *De vita libri tres,* is acknowledged to be a direct development from his commentary on the *Enneads.*

Ficino's successors were many: Andrea Cattani, Pietro Pompanazzi, Giovanni Pico della Mirandola, Angelo Poliziano, and many beyond the Florentine circle were influenced and took up the mantles of Neoplatonism and Hermeticism. However, Heinrich Cornelius Agrippa von Nettesheim (1486–1535), who penned the later *De occulta philosophia libri tres* (1533) wrote what is considered to be the next great *summa* of Renaissance magic. In this work, theurgy and mechanical statue-animation feature separately, divided by the gulf between their operative principles. In the former, "celestial, vital, intellectual, and divine" influences come into play as in the living statues of the *Asclepius* text cited by Agrippa. Agrippa was certainly well aware of the *Hermetica*'s contents; in 1515, his discourses on Hermes Trismegistus had earned him the degree of doctor in the faculties of medicine and law at the University of Pavia. However, Agrippa also admits a gulf between the theoretical possibility and the practical reality of realizing such invested statues, for the only man capable of working true theurgy was one who had attained a union with the Godhead.[29]

On the other hand, Agrippa also cited the moving statues of Daedalus, but he left it unconnected to his discussion of theurgy, stating that though they are examples of wonderful operations, they can nevertheless be produced by mathematics, "without any natural virtue." Agrippa further departed from a strictly mystical approach when he wrote that any magician aspiring to work wonders must be skilled in mathematics.[30]

8.5   Theurgy and Statue-Animation from Late-Antiquity through the Renaissance

The present state of research has not connected any known artwork or object with theurgic practice in the Renaissance, but the transmission of magical philosophy, with its attendant material culture from antiquity through the early modern period underlines the strong possibility for a production of objects which paralleled that of theurgy's associated texts. Although the Hermetic and Neoplatonic methods of god-making's reappearance in the Renaissance can be traced directly to the transmission and translation of Greek texts by Florentine Humanists in the fifteenth century, it did not arrive in a vacuum. Instead, this revival of ideas and practices that had not been entirely extinguished after the collapse of the classical world survived through subsequent antique and medieval cultures and centuries. The Greco-Egyptian wisdom tradition, in philosophy and ritual as well as mechanics and the physical sciences, was identified with and concentrated in the city of Alexandria, founded on the coastal confluence of the Nile River with the Mediterranean Sea in the fourth

[29] Heinrich Cornelius Agrippa, *De occulta philosophia Libri tres* (Leiden: Brill, 1992), I.ii.50; Hanegraaf, "Sympathy or the Devil," 8–9.

[30] Agripa, *De occulta philosophia*, II.i.1.

century B.C. by its namesake Alexander the Great. When its famed libraries and temples were destroyed, much of that legacy transferred to a new crucible, primarily Baghdad under the Abbasid Caliphs, where it mingled with Indian, Iranian, and Syrian influences, ultimately to re-emerge in a new form, dubbed the "Islamic sciences."[31] In these traditions, magical amulets suggest to us just one instance of the transmission of the theurgic ideas and practices of the classical world into physical objects or works of art. That statues could be inferrred to be animated in Renaissance Italy, even partially, through the use of theurgy must be understood within the broader, physical context in which this ancient philosophy was transmitted.

In the Middle-Eastern iteration of Greco-Egyptian magical traditions, we perceive a demonic dimension introduced that was distinct from Hermetic and Neoplatonic methods to draw down "pure" celestial influences; this cultural accretion would also bedevil the Christian West for centuries. Occult sympathies that natural materials were perceived to possess now corresponded to specific "star-demons" rather than the higher spheres or emanations in which the pagan pantheon, and ultimately the All, were fixed. In this respect the *telestikè* of the theurgist operated on much the same principles as the talisman of the magus: the placement of the former within a cult statue to invest it with a living spirit is a small step from the inscription on a talisman to establish the same kind of sympathetic connection with a celestial spirit or, in the post-classical world, a demon or angel.

The manufacture of talismans can be traced to Babylonian and Alexandrian Hermetic texts like the *Kyranides,* the mineralogical treatises of medieval Muslim writers, and the Alfonso X codex from thirteenth-century Castille. The quintessential magical text of this stamp was the *Picatrix*, which, although not completely devoid of demonic operations, concerned itself primarily with instructions on the many ways spirit can be coaxed from its natural dwelling place in the stars and brought down to Earth by various channels. This operative principle rests upon the same understanding of the physical influence of stellar and planetary rays as Neoplatonic theurgy. The manufacture of talismans under exacting astrological conditions, the lists of magical substances with occult properties, the treatment of created images (fumigation, wearing, burying, or burning), and prayers offered up to the planets mirror Hermetic and Neoplatonic ritual and give the sense that the invested cult-statues of antiquity merely "shrank," in a sense, to smaller, but no less powerful, astral images. These talismans were sought-after additions to collections of ruler and Church alike in the medieval period: for example, John, Duke of Berry, was a famed patron and collector of precious jewels. Tsar Ivan the Terrible was an avid believer in the lore associated with the heterogeneous stones in his treasury, and this sentiment was shared by their peers throughout the medieval West.

Marsilio Ficino repackaged the inscribed talismans and unadorned amulets of the medieval magician under Neoplatonic auspices in his *De vita,* which distanced them from the more sordid reputations of magic in the Middle Ages. The rehabilitated

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[31] David Pingree, "Hellenophilia versus the History of Science," *Isis* 83 (1992): 554–563, at 555.

reputation of the magus in the Renaissance was a major factor that permitted the flourishing of magical philosophy in the fifteenth and sixteenth centuries and its consequential effect upon material culture. Scholars identify paintings, architecture, urban design, and even the founding of cities as having been conceived and carried out with the intention to trap quantifiable celestial influences for the benefit of their patrons. One inscribed talisman has been connected to the Medici dynasty, the well-known astrological medallion of Catherine de' Medici (1519–1589), believed to have been intended as a love charm, but so far, in spite of the evidence of an astrological function in other types of artwork production by the same class of patrons in the same time period, Renaissance automata, including but not limited to those at Pratolino, have escaped inclusion within this category. Roger Bacon and Marsilio Ficino both wrote that materials such as stone, lime, gemstones, and metals trapped and held celestial rays for longer amounts of time owing to their density. While historians have connected these and other lists of astrologically-appropriate materials to ingredients in Renaissance painting and architecture, their equal importance to automata is undeniable.

We might today class these artworks and talismans as "magical" and therefore irrational objects, but the understanding of their operative principles, grounded on the belief that celestial rays entered both matter and sense, was a standard belief of university-educated scholars before and during the Renaissance, and can be found in the writings of John Pecham, Robert Grosseteste, Roger Bacon, and others. The production of objects with an astrological as well as aesthetic function in the Renaissance was galvanized by the revival of Neoplatonic and Hermetic philosophy, but at the same time it also perpetuated traditional proto-scientific conceptions of radiation rooted in accepted principles of light and optics.

8.6   Mechanical Statue-Animation from Alexandria to Pratolino

Although the "magical" technique of animating statues developed through the Renaissance from being understood as lures to attract celestial intelligences to a more natural philosophical, and almost mechanical, pursuit of measuring and infusing an object with planetary rays, this was not the driving force at Pratolino which caused the Pan to stand up and sit down, the Galatea to sally forth from her rock-grotto, dragons to drink, or trumpets to blow. The pneumatic and hydraulic devices deployed at Pratolino nevertheless share a common origin with theurgic philosophy in the pagan temple of ancient Alexandria. Ctesibius (c. 285–222 B.C.) and Heron of Alexandria's (c. 10–70) many inventions directly shaped automata and hydraulic devices for over two-thousand years. Some of Ctesibius' works were preserved in the Roman writings of Vitruvius (c. 80–15 B.C.); indeed, the rediscovery of the latter by Poggio Bracciolini (1380–1459) had a tremendous, definitive impact on Renaissance art and architecture. Heronic devices survived in the text of the

Pneumatica, which came to Italy along with many other Greek manuscripts after the fall of Constantinople. A 1582 Italian translation of this treatise was dedicated to none other than Pratolino's chief architect, Bernardo Buontalenti, just 7 years after its translation into Latin from Greek.[32] One perceives the germs of inspiration for works at Pratolino and elsewhere in early modern Europe in the devices that emerged from Alexandria, before filtering down to medieval Europe through the lenses of the Byzantine and Muslim East.

Mechanisms responsible for the thaumaturgic displays in the numerous and lucrative temples of Alexandria were jealously-guarded secrets, but over time this illusionistic technology spread beyond Egypt. In the second century, Irenaeus (130–202) wrote about a Gnostic "miracle worker's" device that made a small cup appear to fill a larger one to the point of overflowing.[33] As we saw above with magical philosophy, when paganism and its temples were outlawed at the close of the fourth century, its knowledge, though fragmented, passed to the East. The temples' currency of wonder generated from stunning displays of man-made, mechanical gods was appropriated by Byzantine and Muslim rulers. Baghdad's House of Wisdom inherited what was left of the Library of Alexandria.

Reports spanning the ninth through the eleventh centuries provide a glimpse of Eastern civilization's flourishing in the mechanical arts. Harun al-Rashid (r. 786–809) relaxed in water gardens with fountains demonstrating a sophisticated command of hydraulics, and with moving, chirping, mechanical birds of classical design executed in gold and silver.[34] This same ruler's gift to Charlemagne of a clepsydra water clock prompted the earliest detailed description of such an automaton in the Latin West. His son and successor Caliph al-Ma'mun (r. 813–833) possessed a similar tree with Heronic mechanical birds, although it is possible he may have simply inherited his father's, and a century later in Sammara, the Caliph al-Muqtadir's artificial tree and mechanical birds were observed standing in the middle of a pool by the visiting Greek dignitary and future Byzantine emperor Romanos Lekapenos in 917.

Over the course of centuries in the Muslim East, further strides in engineering were made that adapted technology from the temples to service and entertainment at the court. Ape-shaped automata gamboled, a band of automata beat their instruments in time, and mechanical servants proffered their masters with a drink and a napkin.[35] This concern with comfort has been recognized as a characteristically Arab contribution to the development of automata later in the West. However, the idea had been present in the Greek literary imagination: the tripods and serving-girls of Hephaestus in the *Iliad* are one example, and similar devices appear later in

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[32] Bernardo Davanzati, *Della natura del voto di Erone Alessandrino* (Firenze: Gargiolli and Martin, 1862).

[33] Irenaeus of Lyons, *Against Heresies,* trans. Dominick J. Unger (New York: The Newman Press, 1992), 56.

[34] Jean Delumeau and Matthew O'Connell, *History of Paradise: The Garden of Eden in Myth and Tradition* (New York: Continuum, 1995), 128.

[35] DeSolla Price, "Automata and the Origins of Mechanism and Mechanistic Philosophy," 16–17.

Philostratus' *Life of Apollonius of Tyana.* Aristotle mused in his *Politics* about the possibility of a "tool [that] could follow orders, or could perceive in advance what is needed and so could complete its work by itself," and a device that could dispense soap and water appears in Greek sources.[36] Engineers such as Ismail Al-Jazari (1136–1206), Ridwan ibn Al-Saati (died c. 1225), and the Banu Musa ("Sons of Moses"), active in ninth-century Baghdad, invented hundreds of devices, and their texts demonstrate how simple Heronic mechanisms harnessed the forces of water and air to animate automata, blow whistles, make organs play, and birds sing. Legendary reports appear further east in India of other automata: wooden men that walked, talked, danced, and sang, mechanical elephants, fish, and courtesans that deactivated if embraced too amorously.[37]

The Byzantine court mirrored the 'Abbasid caliphate in the types of automata documented at Constantinople. In 757, the emperor Constantine V sent an organ, presumably steam-powered, to the court of Pepin the Short. Almost a century later, a certain Leo the Magician created a golden tree with singing mechanical birds for emperor Theophilus (r. 829–842), as well as an automated throne with roaring lions and moving beasts in imitation of King Solomon's legendary original.[38] The throne and its automata appear in the c. 956–959 court manual *De ceremoniis* written by emperor Constantine VII Porphyrogennetos, and an account by Liudprand of Cremona of his visit to Constantinople in 949 furnishes more details: the throne in the Magnaura Hall could move up and down, two mechanical lions on either side roared and thumped their tails, and different kinds of mechanical birds produced the calls appropriate to their species. It was activated during presentations of gifts by foreign ambassadors in a choreographed ritual. By the High Middle Ages in the West, Byzantium's automata appear to have corroded into immobility: a description left by the soldier Robert of Clari from the fourth crusade testifies to defunct automata of men and women, horses, oxen, camels, bears, lions, and other animals in the Hippodrome of Constantinople.[39] However, some works survived or continued to be manufactured. An eleventh-century report of the visit of Charlemagne to Constantinople describes two bronze infants, which during a storm turn to look at each other and produce life-like laughter. Elsewhere, travelers encountered mechanical angels, which blew trumpets, and mechanical horsemen that announced the hours. It would not be long before these same conceits appeared in the West.

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[36] Homer, *Iliad,* trans. Robert Fagles (New York: Penguin Books, 1990), 18.435–440, 488–90; Philostratus, *Life of Apollonius of Tyana,* trans. C. F. Conybeare (New York: The Macmillan Co., 1912), bk. 3, 289–91; Aristotle, *Politics*, 1253b, quoted in Kevin LaGrandeur, "The Talking Brass Head as a Symbol of Dangerous Knowledge in *Friar Bacon* and in *Alphonsus King of Aragon*," *English Studies* 5 (1999): 408–422, at 409.

[37] John Cohen, *Human Robots in Myth and Science* (New York: A. S. Barnes and Company, 1966), 23.

[38] See Gerard Brett, "The Automata in the Byzantine 'Throne of Solomon'," *Speculum* 29 (1954): 477–487; A. R. Littlewood, "Gardens of the Palaces," in *Byzantine Court Culture from 829 to 1204*, ed. Henry Maguire, 13–38 (Washington: Harvard University Press, 1997), 32.

[39] Robert of Clari, *The Conquest of Constantinople*, trans. Edgar Holmes McNeal (New York: Columbia University Press, 1936), 109–110.

A number of these innovations filtered into Europe: clepsydra and astronomical clocks, singing birds, musical organs, mechanical simulacra of man and beast, table-fountains, rising thrones, angels, and fabulous trees appear at medieval courts. Visconti gardens of the fourteenth century in Pavia and Milan possessed Heronic, singing mechanical birds. The water gardens of Muslim Sicily, exemplified by surviving sites such as Palermo's Zisa Palace, impressed one crusader so much that he built his own version when he returned home to France.[40] The result was the c. 1270 castle and park of Count Robert d'Artois at Hesdin with its mechanical toys and aquatic illusions, which was an unparalleled gathering of diverse mechanical works that anticipated the vast hydraulic gardens of the Italian Renaissance, and particularly Pratolino.[41] Many features seem to have been taken directly from Islamic models: moving wooden statues were animated by cords and water conducted through metal pipes. Hydraulic automata included an elephant, goat, and stag, a carved tree covered with birds spouting water, and mechanical apes covered in real fur (horns were added to the apes in 1312). These automata were present from the late-thirteenth century through the mid-fourteenth. Most of these medieval *engins* were destroyed when Hesdin was ravaged in the Hundred Years' War by Edward III of England, but when the site passed to Duke Philip the Good of Burgundy, renovations of what was left, as well as original inventions, brought spectacular developments in the early fifteenth century: fountain jets were hidden under stairs, in the pavement, and in benches, adapted to surprise and soak unsuspecting guests. In a room equipped to create the illusion of thunderstorms with rain, lightning, and even snow, there were eight pipes below for "wetting ladies" and three pipes which "whitened" guests with flour when they stepped in front of them. If they tried to escape, more jets blocked their exit. Welcoming visitors to the room was a valet of wood with the ability to speak (believed to have been via a hidden speaking tube, as with certain Egyptian predecessors), and another automaton sounded a trumpet and cried out to guests to leave the room.

In 1553, Hesdin's park, its devices, and the entire neighboring village were destroyed by order of Charles V, shortly before the appearance of remarkably similar works at Pratolino. As at Hesdin, Pratolino's water jets could be either ornamental or "wetting sports" hidden under stairs, stools, benches, and in the mouths of both human and animal automata. Memorable tricks in the "Grotto of the Deluge" were witnessed by Michel de Montaigne:

> … the whole grotto is filled with water, and all the seats squirt water up to your bottom; and, as you fly from the grotto and run up the palace stairs, anyone who wishes to indulge in this kind of sport may let loose from every two steps of that stairway a thousand jets of water, which will bathe you until you reach the upper part of the house.[42]

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[40] See Christine Ungruh, "Die Normannischen Gartenpaläste in Palermo: Aneignung einer Mittelmeerischen Koinê im 12. Jahrhundert," *Mitteilungen des Kunsthistorischen Institutes in Florence* 51. Bd., H. ½ (2007): 1–44.

[41] Marguerite Charageat, "Le parc d'Hesdin, création monumentale du XIIIième siècle, ses origines arabes," *Bulletin de la societé d'histoire de l'art français* (1950): 94–106.

[42] Montaigne, *Journal de voyage en Italie*, 185–186.

Fig. 8.9 Giovanni Guerra,
*Il di dietro della spelonca
dopia del cupido girante e
varii giuochi*. Albertina
Museum, Vienna. 1601

In Pratolino's park to the south of the villa, a mound-shaped grotto (one of the few structures to survive intact to the present day) originally housed a cupid statue, now lost, with a torch in upraised hand, bow and four arrows in the other which would rotate gently, squirting water from its torch in the face of the curious without warning. As for the benches, they too were treacherous because streams of water would shoot out where feet would pass. The perforations in the floor seen in Guerra's interior perspective of this grotto likely indicate even more jets of water, fulfilling Francesco De' Vieri's description that this grotto was "all tricks for whoever entered unwittingly would find themselves wet whether they sat down or stood up."[43] Furthermore, thin water jets of this kind were remarked upon by an anonymous visitor in the eighteenth century (Figs. 8.9, 8.10, and 8.11):

> The Grotto of the Deluge is thus named from the abundance of its waters, which gush not only from walls and ceilings, but from the pavement. Soon as the visitor has entered, he is a prisoner and at the mercy of his guide. Jets d'eau start up from the threshold, and bar his egress: and should he dash through this liquid barrier, the jets follow him to the esplanade,

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[43] De' Vieri, *Delle Maravigliose Opere di Pratolino*, 53.

Fig. 8.10 Giovanni
Guerra, *Tavolo gioco
d'acque in vario scherzo
con otto luochi per il
convitati ove sempre fresca
concore*. Albertina
Museum, Vienna. 1601

the mosaic pavement of which is perforated with small ducts, from which dart innumerable
jets as fine as thread.[44]
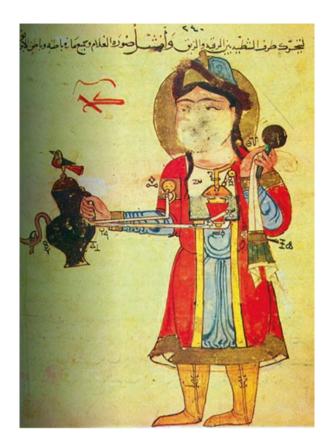
Pratolino also replicated the idea of mechanical servants seen at Hesdin and
Islamic courts and encountered otherwise in fantastic medieval literature.[45] The vil-
la's ground floor's most innermost grotto featured water flowing into eight place-
settings carved out of a central granite table, and food was provided by a wheel
corresponding to the kitchen, which De' Vieri wrote was for the occasions when
Francesco I did not wish to be served by any human attendants. However, the apex of
the experience at Pratolino of being served by non-human servants was undoubtedly
the stone page described by De' Vieri in the same room, which poured water for visi-
tors from a pitcher in his hand.[46] Another drawing from the same series by Giovanni

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[44] Anonymous, "Letters of an Artist on Italy, 1798," 574.

[45] For example, the mechanical servants encountered in Hector's "Chamber of Beauty" in the
twelfth-century *Roman de Troie* by Benoît de Saint-Maure. See Benoît de Sainte Maure, *Le Roman
de Troie* [1165], ed. Léopold Constans, 6 vols (Paris: Firmin Didot, 1904–1912), vol. 2, 13, 293–
298, 341–409. See also Lorraine Daston and Katherine Park, *Wonder and the Order of Nature*
(New York: Zone Books, 2001), 89; Minsoo Kang, *Sublime Dreams of Living Machines: The
Automaton in the European Imagination* (Cambridge, MA: Harvard University Press, 2011).

[46] De' Vieri, *Delle Maravigliose Opere di Pratolino*, 37.
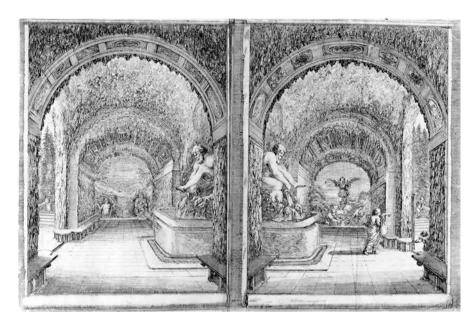
Fig. 8.11 Al-Jazari, *Illustration of a Mechanical Serving Girl* from *The Book of Knowledge of Ingenious Devices*, 1206

Guerra shows the page in front of the octagonal table with what looks like a towel draped over his other arm in an attitude reminiscent of the serving-girl automaton first seen in Al-Jazari's 1206 *Book of Knowledge of Ingenious Mechanical Devices*.

There is a potential connection between Al-Jazari's thirteenth-century treatise and Pratolino's wonders via none other than Leonardo da Vinci (1452–1519). Embodying the ideal of the Renaissance polymath, volumes have been written about Leonardo's contributions to art, mechanics, anatomy, biology, and engineering, to name only a few. Leonardo's familiarity with Islamic and Hellenistic engineering texts may be read as the undergirding for much of his advanced machinery. Take, for instance, a water suction device illustrated in Al-Jazari's works; a virtually identical design appears in works of the fifteenth-century Italian engineer Mariano di Jacopo ('Taccola', 1382-c. 1453) and the Sienese engineer Francesco di Giorgio Martini (1439–1501). Leonardo da Vinci was familiar with Martini's work, evidenced by his hand-written notes in the margins of one of Martini's treatises, and also possessed an extremely rare work on hydraulics by Philo of Byzantium, whose works were largely unknown in the West even through the twentieth century.[47] We

[47] Specifically, the *Trattato di Architettura Civile e Militare*, MS. 282 (Ashburnham 361) in the Biblioteca Medicea Laurenziana of Florence; see Vezzosi, "'Pratolino d'Europa,' degli antichi e dei moderni," 19–20.

Figs. 8.12 and 8.13   Giovanni Guerra, *Grottoes of Pan and Fame*. From Bernardo Sansone Sgrilli, *Descrizione della Regia Villa, Fontane, e Fabbriche di Pratolino* (1742), pl. 4

know that Leonardo designed and successfully executed programmable robots during his lifetime, including a walking Lion for the king of France, a knight automaton for Ludovico Sforza in Milan, and a programmable cart likely intended for a Medici patron (Figs. 8.12 and 8.13).[48]

However, many of Leonardo da Vinci's designs that never left the page, including the clepsydra, are found brought to life at Pratolino by Buontalenti and others, making Leonardo da Vinci, in a sense, the uncredited genius behind many of its wonders. At Pratolino, we see the clepsydra principle credited by De' Vieri as the operation derived from antiquity that powered a tableau of automata in which a winged figure of Fame sounds a trumpet while a peasant below offers a cup to a dragon who, by means of a siphon, appears to drink from it.[49] This siphon mechanism was known in Europe already for centuries, and the Pratolino dragon's operation appears to be essentially that of the "cantepleure" in the c. 1220–1240 sketchbook of Villard de Honnecourt in the shape of a bird which "drinks" wine from a bowl.[50] The "Grotto of Fame," as the space housing this tableau was known, was documented in a drawing by Giovanni Guerra as well as an engraving in the

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[48] Jacob Burckhardt, *The Civilization of the Renaissance in Italy* (Vienna: Phaidon Press, 1937), 215.

[49] De' Vieri, *Delle Maravigliose Opere di Pratolino*, 62.

[50] Villard de Honnecourt, MS. fr. 19093, fol. 9 in the Bibliothèque Nationale de France; see Stephen N. Fliegel, "The Cleveland Table Fountain and Gothic Automata," *Cleveland Studies in the History of Art* 7 (2002): 6–49, at 14.

later series by Stefano della Bella. It was the pendant to the Grotto of Pan in the ruined mezzanine-level complex whose shell still sits *in situ.* Mechanical birds, animals, and musical instruments visible in Leonardo's drawings were also witnessed elsewhere at Pratolino by Michel de Montaigne.[51]

8.7   Magical and Mechanical Evidence at Pratolino

With the mechanical knowledge of their workings, why did people like De' Vieri continue to think it possible—even if only in distant antiquity—that occult forces might be responsible for the wondrous motions of the automata? Although invisible, evidence of the workings of occult spirits was provided in authoritative texts, and such spirits, moreover, were not perceived to be outside the gambit of natural causation. The engineer in this tradition could not be precluded from engaging nature through subtle, occult channels held to be equally effective as the more traditional mastery of natural physics required in constructing bridges, dams, forts, or engines. In this sense the *artes theurgices* offered a theoretical matrix which provided the medieval and early modern engineer and his clients an armory of advantages.

Furthermore, by the late sixteenth century the work of "preternatural philosophers" like Marsilio Ficino, Pietro Pomponazzi, Girolamo Cardano, and Giambattista della Porta had bequeathed to late-Renaissance culture the perception that natural forces, rather than the supernatural, were the prime causes of all kinds of phenomena. Yet herein lies a minefield of dissonance for our modern perspective: with few exceptions, astral, astrological, and unseen sympathetic bonds (phenomena that today we would categorize as "magical") were held to be just as natural, quantifiable, and to a certain extent predictable as the action of more conventional natural elements like air and water.[52] The problem of evidence consequently comes down to the difference between the visible and the invisible. One need only think of Isaac Newton's postulation of gravity, evidence for which was furnished by his mathematical language of calculus, and was thus invisible to the eye, if not the mind. Contemporaries dismissed gravity as an occult force in part because of its lack of visible proof. Much the same can be said about the situation surrounding Pratolino. For De' Vieri and his contemporaries, the occult forces that might operate to make the automata move found their evidence not through the possession of a visible aspect, but in a Hermetic and Platonic worldview which rested upon the authority of ancient texts and traditions. These two types of evidence—the textual and the

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[51] Montaigne, *Journal de Voyage en Italie*, 185–186.

[52] For example, the c. 1370 *De causis mirabilium* of Nicole Oresme and the later work of Henry of Hesse, which attacked the edifice of astrology, ranging from diviniation to the theory of celestial influences. See Daston and Park, *Wonder and the Order of Nature*, 130–131.

experiential—could not be in contradiction because the Renaissance's expansive understanding of nature permitted both to operate equally and simultaneously.

It can be argued that De' Vieri's description relied less on the material evidence of Pratolino (he writes that he only spent one day at Pratolino and one hour in consultation with Buontalenti) than the philosophical framework informing the other treatises he composed for Francesco I.[53] Neoplatonic philosophy fascinated him as well as his namesake, who wrote on Ficinian Neoplatonism two generations prior. De' Vieri struggled to receive permission to lecture on Platonist philosophy at the University of Pisa, and although he eventually received permission from Joanna of Austria, Francesco I's first wife, his lectures were halted by his colleagues' outcry.[54] However, in courtly circles, De' Vieri was not so restrained; rather, it appears he was encouraged by his patron to explore the outer limits of philosophical inquiry. De' Vieri's 1587 description of Pratolino not only alludes to theurgic practices and atomistic philosophy, a highly controversial proposition in post-Tridentine Italy—he even brings up Zoroaster's mandate to "seek paradise" and Pythagoras' doctrine of the trans-migration of the soul, though he dutifully tries to argue that Pythagoras did not really mean what his words seem to communicate.[55]

In the private spaces of Francesco I, his small Studiolo in the Palazzo Vecchio and the expanses of Pratolino, their iconographies have been read as reinforcing the identity of the Grand Duke as divine demiurge; however, whereas Prometheus figures prominently in the central ceiling lunette of the Studiolo, representation of the same figure is all together absent at Pratolino, leading to the supposition that Francesco I himself embodied Prometheus, the bringer of civilization and the founder of technology, while in residence. Whether they be "gods, men, or statues," as De' Vieri wrote, Francesco I presided over a "living" population of his own creation, evidence of which was furnished by their autonomous motion—the crucial criterion of life in Aristotelian and Platonic philosophy alike.[56] And Pratolino's pneumatic and hydraulic devices did in fact draw their motion from natural forces imbued with a life-giving capacity from antiquity onwards.

With this realization, we are brought full-circle to the intersection of magical and mechanical ideas in the early modern period. A chief tenet recognized in the god-making method of the *Asclepius* text is that breath keeps life in all things.[57] For the

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[53] These included Francesco de' Vieri, *Discorso di M. Francesco de' Vieri cognominato il secondo Verino filosofo intorno ai Demoni quali volgarmente sono chiamati spiriti*, trans. Michele d'Antonio Dati (1593). Biblioteca Nazionale Centrale di Firenze (BNCF), Ricciardiana 1092; *Franc. Verino secondo, ragionamento intorno alle stelle recitato nell-Accademia Fiorentina* (1587). BNCF, Magl. Palatino 126 (125); *Franc. Verinus, prelectio in libros Aris(totelis) de physica auscultatione. Id. Epilogus de anima et eius partibus et particulis.* BNCF, Rinuccini, filza 21.

[54] Jill Kraye, "La filosofia nelle università italiane del XVI secolo," in *Le filosofie del Rinascimento*, ed. C. Vasoli and P. Pissavino, 350–373 (Milano: Bruno Mondadori Editori, 2002), 363.

[55] De' Vieri, *Delle Maravigliose Opere di Pratolino,* 49–50.

[56] Ibid., 12.

[57] Thomas Moore, *The Planets Within: The Astrological Psychology of Marsilio Ficino* (Great Barrington, MA: Lindisfarne Press, 1990), 38.

ancient Stoics, *pneuma* meant breath, wind, spirit, and air, and these forces were originally considered interchangeable. For the Hellenistic doctors Erasistratus and Herophilus, *pneuma* was the fluid that coursed through the body's nerves, bringing motion and perception with it. By learning to control that air-spirit with fire, water, and other forces, man did indeed give "life" to inanimate statues in ancient Alexandria, medieval Baghdad, Byzantine Constantinople, and finally in medieval and early modern Europe.

Although air may have been perceived as the instrument, or organ, of the gods, the life-giving properties of water were also recognized in the Renaissance, at Pratolino, and other noted hydraulic villas of the day, as no less than its very soul, the *anima del giardino*.[58] Here again are the two mechanical causal phenomena at work in early modern automata: the pneumatic and the hydraulic. At the close of the sixteenth century, the likening of the Pratolino automata to antique predecessors operated by unseen sympathies speaks to the contemporaneous overlap from the Hermetic and Neoplatonic view of air, stars, and other natural elements understood in no less a mechanical manner. Rather, it is our modern idea of magic that has shifted to encompass all things touched by astrology or pre-modern ideas about the influence of stars, that has occluded the very measurable nature under which these celestial radiations were understood to have operated within nature. At the peak of the development of hydraulic technology fostered by the princely Italian villas, yet before the extinguishing of the pagan spirit by the Counter-Reformation and the substitution of the Mannerist for the Baroque, the Pratolino automata represent a unique and intriguing chapter in the histories of art, technology, philosophy, and science.

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[58] Anatole Tchikine, "'L'anima del giardino': Water, Gardens, and Hydraulics in Sixteenth-Century Florence and Naples," in *Technology and the Garden*, ed. Michael G. Lee and Kenneth I. Helphand, 129–155 (Washington: Dumbarton Oaks, 2014), 129.

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Mark Elling Rosheim

Leonardo's Lost Robots

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Leonardo's Lost Robots

With 203 Images

Springer

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[… You know what they say. In Italy for thirty years under the Borgias they had warfare, terror, murder, bloodshed; and they produced Michelangelo, Leonardo da Vinci, and the Renaissance. In Switzerland they had brotherly love, five hundred years of democracy and peace. And what did they produce? The cuckoo clock …]

Orson Welles in *The Third Man*. Directed by Carol Reed, 1949

Foreword

As this book is bound to be hailed by the academic world as one of the most significant and original contributions to scholarship, and this in spite of its being by a non-academic author, the general reader should welcome it as a refreshing change of pace in the outpouring of banalities and commonplace accounts of Leonardo da Vinci's art and science as well as technology, not to mention the groundless interpretations of his unfathomable mind, personality and character, including his sexuality and even his views on religion, ever so often taking him out of historical and cultural context with dangerously astute fabrications that may show at best how very few are the discriminating readers left.

As is well known, any scholarly work has autobiographical connotations. For Mark Rosheim, they are a necessity, and he is not shy to make them obvious. But it is not only for the sake of clarifying the nature and complexities of a problem of technological interpretation that he would take time to explain how he got to the solution of that problem. It is above all for the urge to share with others the uplifting, exhilarating experience of establishing a direct contact with one of the greatest minds that ever existed. In order to do so, he has gathered all possible reference tools pertaining to the study of Leonardo and his time, sparing no effort to acquire every facsimile and critical edition of his manuscripts and drawings, from the earliest to the latest, as if he were to compete with the most prestigious, comparable collections in long-established public institutions. He turns to such tools with scientific humility, in fact with a sense of great respect for the scholarship that generated them, ever ready to indulge in moments of innocent delight, as collectors normally do, at the beauty and fascination of masterpieces in book production. One would hardly expect this from a young man well grounded in the reality of a demanding if not ruthless world of business and professional achievement that seldom allows for intellectual leisure. And yet his scientific and technological visions are well cast into the future, to which he is contributing with relentless dedication and unfailing expertise. His numerous patents in the field of robotics are eloquent proof of this. It is a field that he keeps approaching historically. His two books on the subject of robotics show that he is indeed in the privileged position of turning to his fellow engineers of the past, notably but not exclusively Leonardo da Vinci, and understanding immediately the working of their minds. As a skillful draftsman, he shows a sort of elective affinity with Leonardo's way of conveying an idea by drawing. And then, determined to go beyond this, he has set himself to learning Italian so as to follow him carefully in his explanatory notes and even in the complexities of his theoretical writings as well. Having to deal with Leonardo's technological conceptions of which, very often, only a preliminary, fragmentary phase is left, he is now prepared to fill the gaps, so to speak, by figuring out what is missing—just like an archaeologist who recreates a lost masterpiece. And so, for the first time, he can tell the fascinating story of Leonardo's lost robots.

This is an extraordinary book that, to an old and lonely wolf the like of myself, brings joy with gratification. It is a book that answers so many questions that I have raised in the course of half a century, questions which I have long thought that only the improbable, though not impossible, discovery of Leonardo's missing manuscripts

or comparable documents could have answered. I would never have thought that a brilliant young man, so far from the fervor and tradition of Leonardo research, could possibly come my way to follow in my footsteps with all the power of his Yankee ingenuity and with the pristine candor and generosity of a fellow American. Now more than ever I could tell myself that I always wanted to be the teacher I never had and to have the student I never was. Mark is that student.

Carlo Pedretti, Fall 2005

Preface

Milan, Italy, 1495. Leonardo da Vinci designed and possibly built the first articulated humanoid robot in the history of western civilization. This armored Robot Knight was designed to sit up, wave its arms, and move its head by means of a flexible neck, while opening and closing its anatomically correct jaw. Quite possibly it emitted sounds to the accompaniment of automated musical instruments such as drums. Leonardo's robot outwardly appeared as a German-Italian suit of armor of the late fifteenth century. It was made of wood with parts of leather and brass or bronze and was cable-operated. It may have been built for a grotto, similar to those built at a later date in France.

Madrid, Spain, Winter 1965. Leonardo's *Book of Mechanics* circa 1495, known to scholars as Madrid MS I, and its companion volume, Madrid MS II, are discovered in the National Library of Madrid by André Corbeau. Bound in red Moroccan leather, Madrid MS I originally consisted of 382 pages. Sixteen of Madrid MS I pages are missing. Was the missing material removed at the time of discovery? Interviews are conducted, no one is blamed, and the case is closed. But what was on the missing pages?

Tama, Iowa, Christmas Day, 1965. A red-headed tyke of five years is tearing the wrapping paper off a box and clawing open the flaps held by copper staples. Inside is the red and blue *Lost in Space* Remco toy robot from the Sears Christmas Catalog he had asked Santa for. How vividly he had imagined its every life-like move: the huge reach of the thing, its powerful yet dexterous claws, its rolling gait, its many victories against hostile aliens and, most importantly, its role as the constant companion and guardian of Will Robinson, the youngest member of the TV show's space family. He crawls on the floor with the robot's body flashing, his eyes shining as he watches the robot roll along its preset path. But its arms don't move. The boy stares in disappointment. "What's wrong with it, Dad?" "Nothing, Mark. You can move the arms yourself by squeezing the levers in its back." "But it's a robot. They're supposed to move on their own."

He spends the next years obsessed with building robots out of TinkerToys and cardboard boxes. And the year after that, too. It is not only his toy robot that is flawed. They are all flawed. No modern robot has ever moved the way a human being moves because most of them are made up of joints that are little more than strong hinges swinging stiffly in one dimension, or are driven by simple motors held together with brackets—joints that jam and lock up.

In 1972, he watches the multi-part *Life of Leonardo* sponsored by Alitalia Airlines. With dramatic music, authentic settings and a superb supporting cast, the film intrigues him with the successes and failures of the ultimate Renaissance man. Although he does not know it, he is also introduced to the research of Carlo Pedretti who, decades later, would become his mentor. Towards the end of the 1970s, the boy, now a young man, begins to assemble a small library of Leonardo books.

In search of an understanding of human motion, he studies the anatomical drawings of Leonardo da Vinci. He learns how muscles are located *close to*, but not *on,* the joints they move—a feature that gives them both lightness and power. He learns how our most flexible joints move in two or even three dimensions at once, stabilized by

tendons and ligaments. By the early 1990s his research, funded by NASA, leads him to build the Robotic Surrogate, the first humanoid robot with a torso and fully functioning shoulder, elbow, wrist and finger joints.

While researching the first, historical, chapter on robots for his second book, he learns of Carlo Pedretti's pioneering studies of Leonardo's robots. He seeks the master scholar, who inspires him to begin his own research that would lead him on an odyssey around the world.

I was that boy. I am that man. My quest to build a robot with human-like capability—an anthrobot—has taken me on a journey that started with the ancient human urge to build a creature in man's own image. I followed in Leonardo's footsteps, and they led me not only to the solution to the mystery of the eight missing folios (sixteen pages) of Madrid MS I, but also to my reconstruction of Leonardo's Robot Knight. This book tells the story of its reconstruction and those of two other of Leonardo's automata: the programmable cart that may have transported a lion *rampant,* and a "digital," hydraulically powered clock that told the hours.

St. Paul, 2005
M. E. R.

Acknowledgments

I wish to thank the close friends who assisted in this undertaking. Without Carlo Pedretti's generous spirit and support, my work on Leonardo would never have gone as far as it has. It is to Carlo that this book is dedicated. Thanks to my editor, Mary Ann "the other half of my brain" Cincotta, without whose shaping, chopping, pruning, and nurturing, this book would also not exist. I would also like to thank the staff of the Florence Science Museum and Sforza Castle in Milan, the Biblioteca Leonardiana in Vinci, the University of Minnesota Library rare books department, British Library, Dr. Gerald Sauter for his wonderful and well thought-out electronic analog of Leonardo's Bell Ringer, Jack William Smith for transforming my detailed photographs and sketches into the classic illustrations you see here, John Kivisto for the splendid CAD renderings, last but not least Springer's layout artist Armin Stasch extraordinaire. Tom Ditzinger my Editor at Springer whose rare talent for technical and literary insight made this book a reality. *Per aspera ad astra.*

St. Paul, 2005
M. E. R.

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Beginnings

Constancy. Not who begins but he who perserveres.

Leonardo da Vinci MS H^3, f. 101 r, c. 1494

When I set myself to the task of writing a historical introductory chapter to my second book, *Robot Evolution,* in the early 1990s, I had learned about Leonardo's Robot Knight from Carlo Pedretti's magnificent *Leonardo Architect*.[1] I had seen the book in a book store, but it was in Italian and very expensive. Later I found a copy of it used and in English. After digesting it I leapt at the opportunity to delve into Leonardo's Robot Knight, which was described near the end of the book. Taking a leap of faith that enough material had survived to reconstruct the robot, I made my way to the University of Minnesota's Rare Books Collection on the top floor of Wilson Library. There, an elderly librarian, tasked with wheeling up from the stacks the twelve elephant folios of the Codex Atlanticus, nearly collapsed his cart beneath the volumes, which weighed several hundred pounds. From this awkward beginning I traced the faint fragments one by one, perhaps even discovering an overlapping figure that had been overlooked by Pedretti, and was able to make a road map of the design and publish the fragments. My book, *Robot Evolution*, which contained the Leonardo material, was well underway but not yet published by the winter of 1994.

While in Los Angeles in February that year, where I had gone to recover from another of my bouts of chronic bronchitis brought on by the harsh and unyielding climate of Minnesota, I found myself with little to do. On a whim, I decided to contact Pedretti himself. I called and left a message at the UCLA Arts Library on Hilgard Avenue. He returned the call to my Santa Monica budget hotel room and after a lengthy conversation, I proposed sitting in on his lecture. Suggesting that for "people like you" it would be best if I came to his house for an in-person discussion, he graciously invited me to his home in Westwood.

Driving down the endless car dealerships, restaurants, and other commercial establishments on Santa Monica Boulevard, I passed under Interstate 405 and continued on past the sprawl of Kinko's and Subway sandwich shops. As I turned off I entered a tree-lined, peaceful neighborhood whose beauty is favored by artists, educators and scholars. Walking up the sidewalk to his beautiful Spanish Colonial home with its shady, well groomed yard, the "Armed Response" security sign in front and notes to deliver packages to the neighbor across the street, I began to wonder if I would find the great man at home.

I shouldn't have worried. Carlo Pedretti opened the door and invited me to "Come on in!" I was met by a gracefully aging energetic man with inquisitive brown eyes and an Italian accent. He led me along a narrow hall lined with paintings and prints, and I realized that I had entered the world of a great scholar.

Author of a shelf of books and editor of several "Monumental Leonardo Works in Facsimile" for Giunti, Carlo Pedretti seems to embody the word "Scholar." Professor Emeritus of the UCLA Art History Department, he is better known in Europe, where he maintains a second home in Vinci, Italy, the birthplace of Leonardo.

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[1] Carlo Pedretti, *Leonardo Architect.* New York, Rizzoli International Publications, 1985.

Born in Bologna in 1928, Carlo began his professional life as an artist and journalist. In nearly sixty years of research he has produced a shelf of books the backbone of modern Leonardo scholarship. His most recent and spectacular achievement was the discovery of a previously unknown terracotta angel by Leonardo at San Gennaro near Vinci. The Angel's face is a self portrait of Leonardo himself.[2]

His Westwood living room was filled with antique furniture, an ornate marble fireplace, and a bookcase so large that the front windows of the house had to be removed to bring it into the house! Peering through the ornate grating of that bookcase, I spied a fortune in Renaissance first editions. Pedretti ushered me to the right, into his spacious, book lined office painted in water green with plaster filigree encircling the ceiling. The overhead light was very Leonardo: a geometric sphere design. In a corner stood an ornate scale, the only piece to survive from a 1952 exhibition. On top of a book case a renaissance bronze lamp sat with implements dangling on chains to service the wick.

We discussed his rare books collection, including early editions of Vitruvius. I mentioned I had bought a copy of Vitruvius' *Architecture* and he asked what edition, to which I innocently replied "Dover"—the celebrated budget publisher. This to the man who had (in multiple copies) some of the rarest editions of Vitruvius in existence. Saying it was time to "bring me up to date," he began, with the enthusiasm of a twenty-year old and not a whiff of condescension, to educate me about the various editions of Leonardo facsimiles. He showed me the Giunti facsimiles of the Codex Hammer which he had edited (the original had been purchased by Bill Gates for 30 million dollars). One funny thing that happened was when he was showing me a very rare, early printed book he accidentally tore the page and then rubbed the two pieces together as if they would miraculously heal. Then he brought out the Codex Hammer sixteen-page facsimile notebook from a massive brown leather Solander box, exclaiming in his wonderful, flamboyant Italian way: "Look at this! Magnificent!"

The manuscript, and many like it, had been admired centuries before, while Leonardo was still alive. Antonio de Beatis, who accompanied the Cardinal Luigi of Aragon on his visit to Leonardo's retirement chateau at Cloux, France on October 10, 1517, was astounded to see an "infinity of volumes" pertaining to machinery, hydraulics, anatomy, and of other fields of study.[3]

Leonardo's student and eventual heir, Francesco Melzi, held the collection together and worked towards publishing his book of paintings. Unfortunately, upon Melzi's death, his son Orazio saw little value in the old papers and their dispersion around the world began. Many came into the possession of the Spanish court sculptor and pupil of Michelangelo, Pompeo Leoni. He is responsible for mutilating a great deal of material in the course of creating thematic albums now known to the world as the codices of Leonardo.

In the intervening centuries, many of the codices would be bought and sold and if lucky deposited into libraries around the world by far seeing benefactors. Often named for their owners or the country where they finally came to rest, they bear names such as Codex Atlanticus (so named for its oceanic size); Codex Forster, named for John Forster, who in 1873, donated them to the Victoria and Albert Museum in London. In 1796 Napoleon looted the Ambrosian Library while in Milan, declaring "All men of genius … are French."[4]

The legacy currently consists of over 7 000 pages of notes, some in fairly coherent notebooks much as Leonardo left them. Most of this legacy has been published twice

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[2] Carlo Pedretti, "Un angelo di Leonardo giovane," in the Sunday Cultural Supplement of *Il Sole 24 Ore*, April 19, 1998, no. 106, p. 21.

[3] Antonio de Beatis (1905) Die Reise des Kardinals Luigi d' Aragona durch Deutschland, die Niederlande, Frankreich und Oberitalien, 1517–1518. In: Pastor, Ludwig (ed) Erläuterungen und Ergänzungen zu Janssens Geschichte des deutschen Volkes, vol. 4. Herder, Freiburg.

[4] Kate Steinitz, *Manuscripts of Leonardo da Vinci*, Los Angeles, Ward Ritchie Press, 1948, p. 12.

in facsimile form around the turn of the last two centuries. My first impression upon learning this was to marvel at the large quantity of material. But later, after study, I mourn how much has been lost. The addition of the two Madrid manuscripts, discovered in 1965, added by twenty percent to the known material. The most beautiful of which was also the most vulnerable.

On our way to visit Carlo's magnificent white stucco library, which is housed above his custom-built garage with its red tiled roof, we climbed up some exterior side steps leading to the door. Turning about, I looked up at the ceiling corners and behind me to gauge proportions and recognized Leonardo's proportions: a perfectly square floor plan and a Renaissance style pitched ceiling. Gratified that I had understood the geometry of Leonardo in practical application, Carlo told me that he had driven the contractor mad by insisting on geometrical proportions.

I asked for his comments on the Leonardo material I was working on for *Robot Evolution* (he loved the traced fragments and exclaimed that all the drawings should be done that way). I asked him to review the manuscript and he thanked me for making reference to his work. Plying me with gifts of offprints and books, he asked me to write a paper for his journal, *Achademia Leonardi Vinci*. The subsequent paper was reported in the press and led to my first BBC appearance on their *Tomorrow's Worlds* program.[5]

❖

What can be said when the perfect pairing of teacher and pupil meets? The pupil assimilates the teacher's life experience, not only saving an enormous amount of trial and error, but time. One does not exactly absorb all his detailed knowledge, but perhaps more importantly, his "feel" for his subject. Meeting Carlo enabled me to leapfrog past the usual need for academic training in art history and immediately begin using my knowledge of mechanical design to reinterpret Leonardo's legacy.

Likewise, building on an ancient heritage, Leonardo's training and research provided him with the skills to construct automata, the term used in the Renaissance for robots. His own teacher, Andrea del Verrocchio (1435–1488), was known in Florence as the premier armorer of the second half of the fifteenth century, and some of Leonardo's early drawings reflect this aspect of Verrocchio's workshop activity. Verrocchio also designed and built an automaton clock in the "New Market" (destroyed and now replaced by unremarkable nineteenth-century architecture) which was regarded at the time as a beautiful and whimsical thing.[6]

Illegitimate, Leonardo had little if any contact with his mother and was sent to Verrocchio's bottega, a form of arts and crafts boarding school, as a teenager. Although details of Leonardo's and Verrochio's interaction are undocumented, it is known that Verrocchio loved geometry just as well as art. From him, Leonardo learned drawing, geometry, grinding pigments, painting, sculpture, carpentry, and metal working. Even before Verrochio's tutelage, the young Leonardo showed early promise in his fields. Commissioned to paint a circular panel, he collected snakes and other creepy crawlies and produced a Medusa so detailed and lifelike that it scared his neighbor. Knowing a good thing, his father Ser Piero sold it in the city for a tidy sum and gave a much more mundane shield painted with a heart pierced by an arrow for his peasant tenant.[7]

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[5] BBC, "Tomorow's World." August 12, 1998, producer: Lucy Dudman.

[6] Cf. C. P., "Leonardo's Robot," in *Achademia Leonardi Vinci*, X, 1997, pp. 273–274, quoting Vasari, III. 375, as first noted by Simona Cremante, who suggests a relation with Leonardo's later project for a bell ringer (Windsor, RL 12716 and 12688): "È anco di mano del medesimo [Verrocchio] il putto dell'oriuolo di Mercato Nuovo, che ha le braccia schiodate in modo che, alzandole, suona l'ore con un martello che tiene in mano: il che fu tenuto in que' tempi cosa molto bella e capricciosa."

[7] Giorgio Vasari, Lives of Seventy of the Most Eminent Painters, Sculptors and Architects by Giorgio Vasari. Edited and Annotated in the Light of Recent Discoveries by E. H. and E. W. Blashfield and A. A. Hopkins. Vol. II. Charles Scribner's and Sons, New York, 1986, p. 377–379.
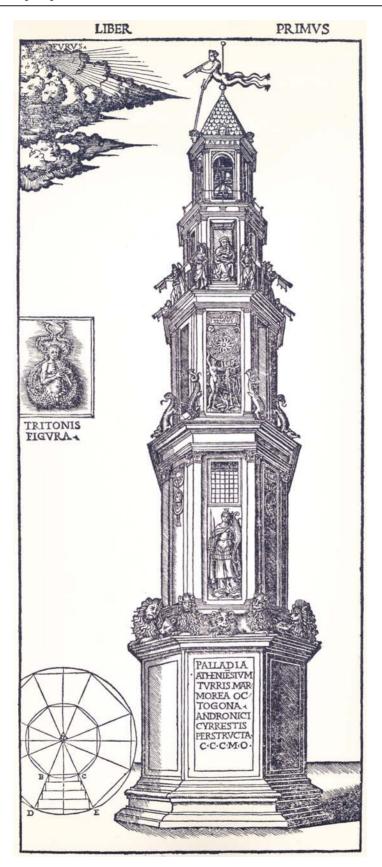
Other practical skills developed during and after his apprenticeship with Verrocchio would have been profitably applied. In Milan, after 1482, he also came in contact with German craftsmen with expertise in armor construction. Using the knowledge he acquired from dissecting corpses, Leonardo built mechanical models of the muscles and joints. His numerous arm-like designs for ornithopters attest to his full understanding of the mechanics of human and animal bodies.

Leonardo's initial impetus to develop robot technology probably came from his exposure to ancient Greek texts as interpreted by the humanists. One example is the well-known account of the mechanical dove made by Archita of Taranto in the fourth century B.C. According to Aulus Gellius, it was made of wood on the basis of "certain mechanical principles," so that "the dove actually flew, so delicately balanced was it with weights, and propelled by a current of air enclosed and concealed within it."[8] Indeed, this seems to be what Leonardo himself is said to have done while in Rome about 1515: "Forming a paste of a certain kind of wax, as he walked he shaped animals very thin and full of wind, and, by blowing into them, made them fly through the air, but when the wind ceased they fell to the ground."[9]

Something that should be kept in mind is that Leonardo had access to ancient texts and perhaps to oral traditions that are undocumented and unknown to us. As Reti writes regarding Leonardo's personal library listing of *Libro di Filone De Acque,* "This is a remarkable entry. The title can refer only to the *Pneumatics* of Philon of Byzantium, who is believed to have flourished about the end of the second century. It is surprising to find such an early trace of an Arabic text which became known to Western scholars only in our twentieth century."[10]

A compelling use of automation for political purposes occurred in ancient Roman times following the assassination of Julius Caesar. This has come down to us from the Roman historian Appian (A.D. 95?–A.D. 165?). A Latin translation by Petrus Candidus, private secretary to Pope Nicholas V, was published the year of Leonardo's birth in 1452 and therefore would have been available to him. Appian tells us that Marc Antony was to deliver the funeral oration for Caesar, with the goal of gaining popular support for punishing the conspirators. An unendurable anguish weighed upon the maddening crowd. The tension was at a fever pitch. The potentially dangerous mob was now struck with a vision of horror:

> While they were in this temper and were already near to violence, somebody raised above the bier an image of Caesar himself made of wax. The body itself, as it lay on its back on the couch, could not be seen. The image was turned around and round by a mechanical device, showing the twenty three wounds in all parts of the body and on the face, that had been dealt to him so brutally. The people could no longer bear the pitiful sight presented to them […][11]

Antony's use of this robotic simulacrum of Caesar was a success in stirring the crowd to action, producing one of the greatest civil war in history.

Although unlikely, it is even conceivable that fragments of ancient prototypes could have been unearthed during Leonardo's lifetime. One wonders, for example, why the Renaissance 1521 Como edition of *De Architectura* by Vitruvius the illustration of the Tower of Winds is festooned with automata when the building has been gutted for centuries (Fig. 1.1).[12] Nero's *Domus Aurea* (golden house)—which was built between A.D. 64 and A.D. 68 on real estate reclaimed from the fire that consumed the downtown of first-century Rome and later replaced by, among other things, the Coliseum—was accidentally discovered in 1480 when a tavern owner excavating for a cellar accidentally dug through to the ancient dwelling. Artists of the day, carrying torches and sketch-

8   Vasari, *Lives*, IV. 46.
9   *Attic Nights,* X. 12, viii.
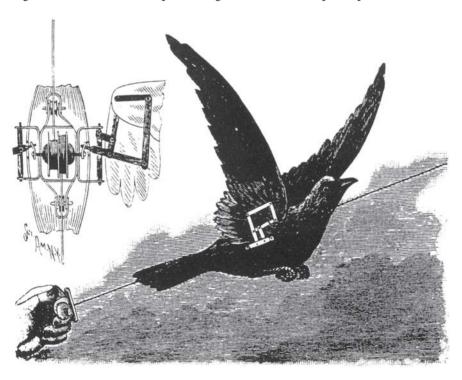10 Leonardo da Vinci: *The Madrid Codices*, vol. 3. Commentary p. 106, McGraw Hill, New York.
11 Appian, *Roman History: The Civil Wars*, Book II 147, p. 499. New York, Macmillan Co.
12 Vitruvius, *De Architectura*. F. XXIII verso, Bronx: Blom, 1968.

books, made their way into the palace and copied the innumerable fresco paintings that covered the vaults, finding in them the source of inspiration for their decorations of palaces, chapels and villas. Raphael, master of the Vatican Stanze, was inspired by the buried frescoes and, along with Giovanni da Udine, launched a new artistic style. The *Domus*, which was buried in order to build the Baths of Titus, was built into the Oppian Hill and contained grottos and a dining room featuring a rotating ceiling that may have depicted the movements of the heavens. Leonardo was a young man at the time the *Domus* was discovered.

The Laocoön, discovered in 1506 in the Dumas's apsidal hall and identified by Michelangelo, which with its tortured, dramatic figures transformed the Renaissance conception of classical sculpture. Leonardo was working in Milan at this time.

About 1508, as he was staging a play at the residence of the French governor of Milan, Charles d' Amboise, Leonardo devised a mechanical bird[13] that could flap its wings by means of a double crank mechanism as it descended along a cable (Fig. 1.2). A comparable device was sold as a toy in the late nineteenth century (Fig. 1.3), and there is of course the antecedent of Villar de Honnecourt in the first half of the thirteenth century (Fig.1.2).

Another bit of evidence supporting the idea that Leonardo had not only the ambition but the knowledge needed to build automata is the Codex Huygens. Recently confirmed to be copies of several folios of lost Leonardo notes, the Codex Huygens is a late sixteenth-century manuscript based on Leonardo's lost original of about the same date (Fig. 1.4). Named for its owner, brother of the famous Christian Huygens, who was credited with the invention of the pendulum clock, the manuscript resides in the Pierpont Morgan Library in New York.[14] It contains history's earliest kinesiology diagrams. As kinesiology deals with the range of motion and degrees of freedom of human joints, the knowledge of it is vital to the conception and generation of anthropomorphic robots.
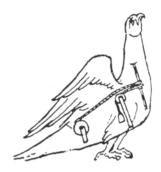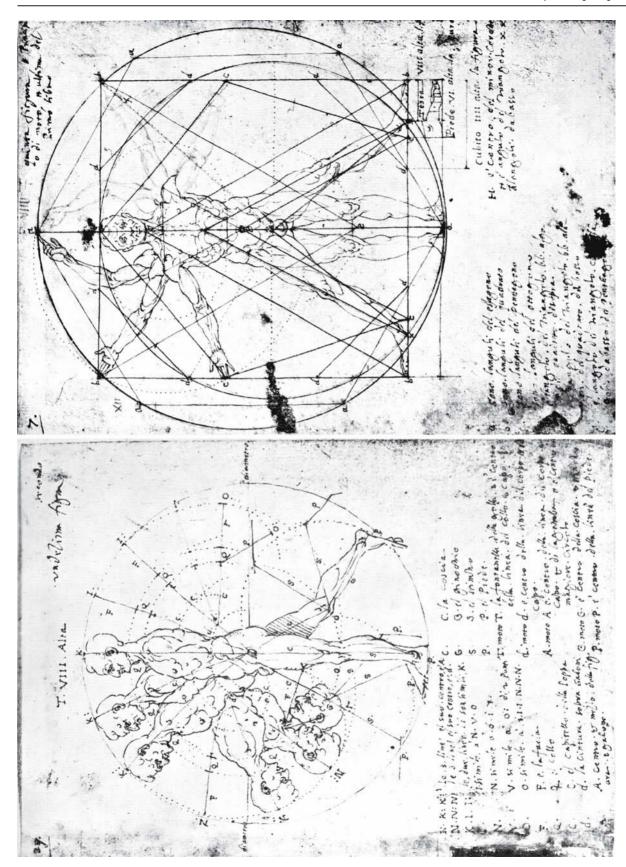
Fig. 1.2. *Top:* Leonardo, CA, f. 231 v-a [629ii v]. *Bottom:* Villar de Honnecourt, sketchbook, f. 58 r, Paris, National Library

Fig. 1.3. Nineteenth century version of Leonardo's bird

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[13] CA, f. 630 v, [231 v-c], 1508, given in the Richter Commentary, note to §703 (with full bibliography).
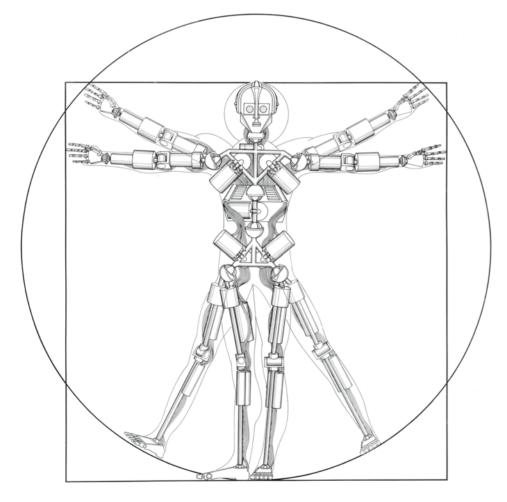
[14] Erwin Panofsky, *The Codex Huygens and Leonardo da Vinci's Art Theory*, London, The Warburg Institute, 1940.

Fig. 1.4. ▶ Codex Huygens, f. 7 and 29

Leonardo's kinesiology diagrams not only provided him with ready reference for his art but also would have enabled him to determine at a glance the range of human limb motion. I know this from my own experience as a designer of robotic joints—much of my early work in joint technology was guided by reproductions of Leonardo's drawings in this codex. Folios 7 and 29, for example, provide a good illustration of the range of motion for legs and arms in a way that is very useful in the design of automata.

My first design for an anthrobot, which formed the cover art of my first book, *Robot Wrist Actuators*,[15] was as much an exercise in art as mechanical design, was inspired by Leonardo's "Proportions of Man." This was based on the ancient Vitruvian canon of proportions (Fig. 1.5). I sought to depict the essential element of an anthrobot by focusing on broad concepts of proportions and kinematics. I applied ball-and-socket joints throughout, but to my surprise, the resultant limbs did not fit the geometrical proportions of the circle and square seen in Leonardo's drawing; I had to "fudge" the limbs to make them fit. I learned two things from this. First, that Leonardo's drawings are very accurate, and may have been drawn with the aid of a *camera obscura* or other optical aid. Perhaps the model stood with his back to a white wall inscribed with a circle and square. Second, I learned that the human shoulder is far more complex than a simple ball and socket—the geometry suggested a compound joint. This would set my direction—study kinesiology to set goals for the robot's performance. And never, never, underestimate Leonardo da Vinci.

Fig. 1.5.
Proportions of Robot

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[15] Mark E. Rosheim, *Robot Wrist Actuators*, New York, Wiley, 1989. Dust Jacket illustration and p. 248–249.

One area, almost a subculture, which I entered through my interest in Leonardo is the world of rare books, their stores, and colorful dealers. I became so interested in it that I started taking night classes at the Minnesota Center for Book Arts in Renaissance bookbinding classes from a local master binder in order to produce my own vintage notebooks sewn on cords.

My addiction started innocently enough with the local bookstores in Minneapolis and Saint Paul, Minnesota. On the other hand, maybe it's something deeper than a simple addiction. I always find myself in the darkest recesses of antique and book stores on the most esoteric behind the scene tours. It seems I'm the last to leave or the only one in some obscure or unlikely exhibit.

Book stores were already familiar to me from years of searching for technical books in my robotics studies. As always, I began by raiding the local stores—Midway Books, Jim Lowry's, The Book House by the University of Minnesota, and later moved on to infiltrating surrounding areas. Constantly I consulted the bibliographies of my ever-growing collection to determine what the standard texts were. And I already had a long history of antique hunting and country auctions going back to my childhood in Tama, Iowa, where for a few dollars I could come home with baskets of silk-covered wire, Model T ignition coils and other wonderful turn of the century technical junk. I would also hunt with my father, who is a collector of rare Horatio Alger books.

Being a rare book addict has its own rhythm and rituals. Hunting down the book, the thrill of discovery and, in this era of the World Wide Web, the tension of ordering, making sure it is still available. Then the joy of receiving the book, with its strange foreign stamps and insurance markings from far away. Stealing off to my little office space nook. Unwrapping the parcel, unpacking the books from the padding—at last reaching the books themselves in their last layer of buff blue colored paper. All alone, delicately removing this sheath to reveal a lost fragment of the past in its impossibly impractical vellum binding. Behold, my new treasure: a piece of history intercepted by me in its travel through time. I have done this countless times, as I amassed my Leonardo manuscripts and facsimiles, down, at last, to the five volumes of the Codex Forster first edition, which nearly completes my collection.

One of my first rare books adventures took place in Berkeley, California, on Telegraph Avenue to the rare books room on the top floor of Moe's Books, then run by the legendary Moe himself. A tubercular man with long gray hair, he was beet red when I first saw him, yelling and screaming about an employee's unproductive behavior. He would be dead of a heart attack a few years later. My first set of Leonardo facsimiles was the Madrid Codices, which I had eyed in a dark hardwood cabinet with double glass doors at Moe's. I sold my Reagan era Stainless Steel Rolex Submariner watch to finance the $300 acquisition and went home well pleased.

Another character in the world of book collecting is Jeremy Norman, the son of the major collector Haskel Norman, a New York psychiatrist who, having passed away to the big library in the sky, no doubt rolled in his grave when his collection was recently sold in three Christie's auctions. The first auction alone netted over six million dollars. Jeremy had an elegant downtown San Francisco suite of offices at 720 Market Street where stockbrokers and lawyers drop 100K on a single purchase. On my visits there I would get his employees in stitches with my impersonation of his nasal voice.

Once I met the French collector Michel Boviar at the Los Angeles book fair and purchased some of the French Leonardo facsimiles from him. When I asked what he liked the most about collecting, he said it was exploring attics of old French estates and finding rare incunabula (books printed before 1500) forgotten there by owners centuries before.

One of the palaces of rare book collecting is the vast and formidable Strand bookstore, named after the famous publishers' street in London. Located at Broadway and Twelfth Street in New York, it boasts five floors and acres of books in addition to its own side entrance rare bookstore, where I picked up a set of turn of the nineteenth-century Leonardo volumes with tipped-in reproductions of his horse drawings.

Passing through the narrow, alley-like streets of Florence, I found Gonnelli, located near the Duomo on Via de' Servi. The bay window is filled with literary treasures flaunting their engraved plates, the artists challenging the centuries. In contrast are the employees, whose perpetual frowns no amount of purchase—even a six-million dollar sale—can reverse into a smile. One employee, thinking that I would not want a broken set, mentioned in passing that they had two volumes from separate sets of Leonardo's Codex Arundel. The employee, surprised that I was interested in such sorry remnants, headed off to the warehouse to locate them. To cut costs I became a connoisseur of the broken set, having faith that someday it will be made whole once more.

One interesting phenomenon of the rare book world is that, not withstanding the value of the objects, dealers are willing to accept checks from anyplace in the world. In the case of the Codex Arundel, my fractured credit card was not up to the job, but by dropping a few well placed names I walked out with the broken set on the strength of my promises to send a check. I guess they figured they knew how to find me. Another learning experience occurred when the State of Minnesota sent me a bill for unpaid customs duties—they too knew how to find me!

Once, in the pre-Web days of Christie's, I stayed up until four in the morning to purchase my first set of the Codex Atlanticus. I had received the notice via "Lot Finder" only a few days previously. I fell asleep by the phone and was woken up by the London auctioneer's call. As the adrenaline pumped through my sleepy head, the hammer went down at only $1 200, and I heard the female auction house representative saying in a firm British voice, "you own it." I wasn't too upset with the price because new copies can retail for over $40 000. Carlo commented that it was meant to be. After purchasing a "mint in box" set I later sold them on eBay to a person who thought he had an original Leonardo painting that he purchased in a flea market. I hope he's right about the painting.

As I amassed my army of facsimiles, storage became a problem. The Codex Atlanticus alone weighed several hundred pounds and took a cubic yard of space. I bought two armoires from Pier One Imports and painted them to resemble school cabinets. I subsequently painted Leonardo's Knight on the wooden panes of one and his lion on the wooden panels of the other.

One day in 1999, Jeremy Norman's rare book catalog "Classics of Science and Medicine" arrived in my mailbox. With my usual sense of anticipation I thumbed through the catalogue, looking for facsimiles of Leonardo manuscripts, and noticed a first edition of *De Motu Animaliam* by Giovanni Alfonso Borelli, a seventeenth-century mathematician, a follower of the great Galileo. The catalogue showed one of his leg diagrams, which I immediately recognized as the same as one in Leonardo's Madrid Manuscript I. Not possessing $7 500 to purchase the first edition, I located a cheap reprint in English with reproductions and commentary. As I was studying the Borelli reproduction, the staggering thought occurred to me that I was not simply looking at drawings that reflected Leonardo's interests and style: *I was looking at the missing section from Madrid MS I.* Could I have located the missing material that had eluded professional scholars for decades? Strangely, the facsimile plates were almost exactly the same size as the Madrid MS I—so you could slip them into the red leather bound facsimile as if they belonged there.

❖

Giovanni Alfonso Borelli was an important mathematician of his time who became interested, as did Leonardo before him, in modeling the movements of animals. Born in Naples on 28 January 1608, he was the son of a Spanish infantryman and his Italian wife. In 1635, through Castelli's recommendation, Borelli obtained the public lectureship in mathematics in Messina, Sicily, then ruled by Spain. In 1658 he accepted the chair of mathematics at Pisa. Malpighi is credited with sparking Borelli's interest in the movements of living creatures. Around 1675, Borelli created *De motu animalium*

in hopes of being received and accepted into the Academie Royale de Science, which had been newly established by Louis XIV in Paris.[16]

The similarities between the work of Borelli and Leonardo have not gone unnoticed by modern researchers. V. P. Zubov makes the general conclusion that Borelli over simplifies.[17] This may be true in some cases but in many other cases he is now viewed as being highly advanced for his time, anticipating technology that did not occur until well into the twentieth century.[18] Zubov also criticizes either the absence or incorrectness of Leonardo's theories of flight. And yet, as shown by Madrid MS I, Leonardo's theories were adequate to design in 1495 a hang-glider capable of lifting a man. This has been proven through modern reconstructions.[19]

Only a very few of the scholars who have dealt with Leonardo's scientific and technological endeavors have called attention to Borelli's work for possible reflections of Leonardo's ideas. None has ever raised the question whether such ideas could have reached Borelli directly or through the mediation of those who had access to Leonardo's manuscripts following his death in 1519.

Those manuscripts were brought back to Italy from France by Francesco Melzi after Leonardo's death. Other books, of course, could have already circulated when Leonardo was still alive, and there is evidence that an autograph manuscript on the movements of the human body analyzed geometrically—a subject extensively treated by

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[16] The best account of Borelli's work, in particular his innovative studies on the flight of birds, is still the one in Giuseppe Boffito, *Il Volo in Italia*, Florence, 1921, pp. 137–142 (with full bibliography). For a comparable account, see Galileo Venturini, S. J., *Da Icaro a Mongolfier*, Rome, Parte Prima, 1928, pp. 243–245, which concludes with a reference to Leonardo: "Nella pare che riguarda il volo, chi volesse fare un accurato confronto, troverebbe le stesse lines maestre, tracciate da Leonardo da Vinci: con questa differenza pero', che mentre Leonardo ci da' (ne' poteva essere altrimenti) un ingegnoso trattatello, dove non se sa se piu' ammirare la intuizione o la succosa brevita' del poderoso autodidatta, il Borelli, che ha potuto far tesoro delle osservazioni sagaci di tanti predecessori, e che in quella materia se sente appieno in casa sua, ci presenta un completo trattato scientifico."

See also the preface to Paul Maquet's English edition of Borelli's *De motu animalium* (*On the Movement of Animals*), Berlin, 1989, pp. v–ix.

Borelli was one of Galileo's most prominent followers, not only as a member of the celebrated Accademia dell Cimento in Florence and as a friend and a colleague of Evangelista Torricelli, but above all as a pupil of Benedetto Castelli, whose treatise *Della misura dell'acque correnti* (1628) was at one time believed to have been based in part on Leonardo's writings on the subject. Cf. Filippo Arredi, "Intorno al trattato 'Della misura dell' acque correnti' di Benedetto Castelli", in *Annali dei Lavori Pubblici*, 1933, fasc. 2, pp. 1–24, and *L'idraulica di Galileo e della sua scuola*, Rome, 1942, in particular p. 16. Borelli's writings on hydraulics are included in the *Raccolta d'autori italiani che trattano del moto delle acque*, Bologna, 1822, vol. III, pp. 289–336. One of his treatises, a report on the Pisa and Livorno swamps ("Stagno di Pisa"), is yet to be examined in connection with Leonardo's previous studies on the subject. Cf. Siro Taviani, *Il moto umano in Lionardo da Vinci*, Florence, 1942, pp. I–LXIV, in particular p. VI for the reference to Leonardo as having recognized before Borelli the general physiological laws of the muscular system.

[17] V. P. Zubov, *Leonardo da Vinci*, Cambridge, Mass., Tr. David H. Kraus, 1968, pp. 184–185. A comparable, modern assessment of Borelli's work comes from Clifford A. Truesdell, the author of a perceptive and well informed essay on "The mechanics of Leonardo da Vinci," in his *Essays in the History of Mechanics*, New York, Springer-Verlag, 1968, pp. 324–325: "In the seventeenth century, statics was a well developed subject, and it was applied in a way then acceptable to many persons in many cases where any modern engineer would require laws of motion, then unknown. For example, we may cite Borelli's book, *On the Motion of Animals* (1685), where the parallelogram of forces seems to be the only quantitative basis for two volumes on the subject named, and where, despite the title, we look in vain for any laws of motion. I do not mean at all to ridicule the book; it is not only truly scientific but also ingenious in many places; I adduce it as an example to show the work both intelligent and extensive can be done on a wobbly foundation, and that the existence of serious literature in a domain, leading to some measure of success, does not necessarily imply that the structure is sound."

[18] Paul Maquet, as cited in note 16 above.

[19] See Michael Pidock, "The Hang Glider," in *Achademia Leonardi Vinci*, VI, Firenze, Giunti, 1993, pp. 222–225, with an editorial introductory note and reproductions, figures 1 and 2, of photographs of a first test flight of the reconstructed hang glider (Sussex Downs, England, 20 October 1993). A version more faithful to Leonardo's drawings has recently been built at Sigillo in Umbria by a local association of hang glider pilots. See Carlo Pedretti, *Leonardo. The Machines*, Firenze, Giunti, 1999, p. 29.
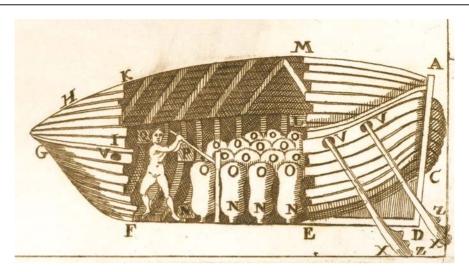
Borelli—was seen by Federico Zuccaro either in Rome or in Turin at the end of the sixteenth century.[20] And since a mechanical lion made for Francis I is now confirmed to have been a Medici commission on which Leonardo worked, either in Florence or in Rome about 1515, he very well may have gathered all the pertinent information in a book left to his patrons and then lost, as was the case with a book of unspecified contents given to Battista dell' Aquila, steward-in-waiting to the Pope—"cameriere segreto del Papa."[21] Leonardo's invention of diver devices and his studies for the submarine were shown by Mario Baratta in 1903 as part of a vast historical context that includes Borelli's comparable studies.[22] Indeed, the diver devices shown in fig. 8 from table XIIII seems to be lifted directly from Leonardo (Fig. 1.6). Borelli might be the source of

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[20] Federico Zuccari's account of the lost Leonardo manuscript of the Codex Huygens type of kinesiology studies is given in his *Idea*, Turin, 1607, p. 31, as fully discussed and reproduced in Leonardo da Vinci, *Libro di pittura. Edizione in facsimile del Codice Urbinate lat. 1270 nella Biblioteca Apostolica Vaticana a cura di* Carlo Pedretti. *Trascrizione critica* di Carlo Vecce, Florence, Giunti, 1995, pp. 42–43.

[21] Leonardo's memorandum in CA, f. 287 r-a780 r [780 r], c. 1514–1515, used to be quoted, as Richter does, §7A, with the addition of the words "de vocie" (On Acoustics) taken to be the title of Leonardo's book, when they are, instead, Leonardo's "label" to an adjacent diagram. This is explained by Carlo Pedretti in his *Commentary* to the Richter anthology (Oxford, Phaidon 1977), vol. I, p. 107.

[22] Mario Baratta, *Curiositá Vinciane*, Turin, 1905, pp. 179–184. See also Francesco Savorgnan di Brazzá, *Da Leonardo a Marconi. Invenzioni e scoperte italiane*, Milan, 1941, pp. 78–79, for the mention of Borelli's project of a submarine as well.

Fig. 1.7.
Borelli's table XIIII, fig. 9
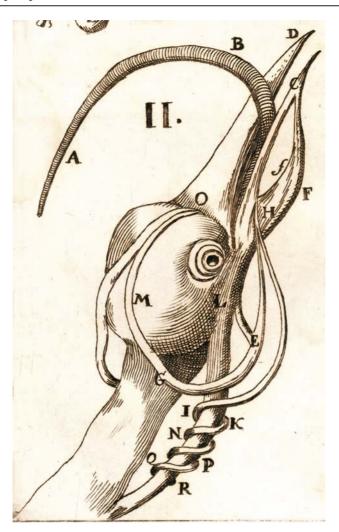
other lost Leonardo drawings. The summary of Madrid MS I discusses how to salvage sunken ships; pages which are now missing may have been discussed and illustrated in folios 37–42 and 55 and 56. It is interesting that Borelli's illustration 9 from table XIIII (Fig. 1.7) seems to illustrate with its leather floats and boarded-up hull just that, albeit with some oars placed through openings.

Borelli's studies on the flight of birds were first mentioned by Gustavo Uzielli in 1884 in connection with Leonardo's Codex on the Flight of Birds, in particular for a note on f. 7 r (and again on f. 10 r), in which Leonardo, long before Borelli, formulated the theory that the wind acts as a wedge in lifting the bird: "il vento fa ofitio di cuneo."[23] Scholars such as Giuseppe Boffito in 1919 and Raffaele Giacomelli in 1935 systematically approached Leonardo's and Borelli's studies on the flight of birds on a comparative basis, and this is also the subject of a paper published by G. Pezzi in 1972.[24]

It is indeed surprising that recent scholars such as Martin Kemp (1982), Kenneth Keele (1983) and Kim H. Veltman (1986), who have greatly contributed to place Leonardo's scientific studies in their historical context, make no reference to Borelli. However, in the Keele-Pedretti edition of the Corpus of Leonardo's Anatomical Studies at Windsor

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[23] Gustavo Uzielli, *Ricerche intorno a Leonardo da Vinci*. Rome, Serie seconda, 1884, p. 403.

[24] The importance and originality of Borelli's studies on the flight of birds were first recognized by E. J. Marey, *La machine animale*, Paris, Librairie Germer Baillière, Bibliothèque Scientifique Internationale, 1873, and again, in a context that includes Leonardo's comparable studies, in roman *Le vol des oiseaux*, Paris, 1890, pp. 234–235, a classic on the subject which is not recorded in Verga's *Bibliografia vinciana* (1931). See also Modestino Del Caizo, *Studi di Giovanni Alfonso Borelli sulla pressione atmosferica*, Naples, 1886, and, by the same author, *Giovanni Alfonso Borelli e la sua opera "De motu animalium,"* Naples, 1908. Raffaello Caverni, *Storia del metodo sperimentale in Italia*, Florence, 1891–1900, 6 vols., in particular vol. III, p. 402; Giuseppe Boffito, *Il volo in Italia*, cit. (as in note 11 above), pp. 137–142 (in comparison with Leonardo); Raffaele Giacomelli, *Gli scritti di Leonardo da Vinci sul volo*, Rome, 1935, pp. 206–207, and, by the same author, "Il *De volatu* di Borelli," in *L'Aeronautica*, XIV, fasc. 3, 1934, pp. 1–15. For the wedge theory in both Leonardo and Borelli, cf. G. B. De Toni, *Le piante egli animali in Leonardo da Vinci*, Bologna, 1922, p. 137. In 1900 G. B. De Toni ("Osservazioni di Leonardo intorno si fenomeni di capillaritá," in *Frammenti Vinciani, I–IV*, Padua, 1900, pp. 53–61) had already mentioned Borelli in connection with Leonardo's experiments on capillarity. G. Pezzì, "La meccanica del volo nell'opera di Leonardo da Vinci e nel *De motu animalium* di Gian Alfonso Borelli", in *Minerva medica*, LXIII, 1972, pp. 2184–2188, and *Annali di medicina navale e coloniale*, LXXVI, 1971, pp. 2750–2782. And finally: Useful information on the life and work of Borelli is still to be found in Giammaria Mazzuchelli, *Gli scrittori d' Italia*, Brescia, Giambatista Bossini, 1762, vol. II, part III, pp. 1709–1714. See also Pietro Riccardi, *Biblioteca matematica italiana*, Modena, 1970, *sub voce*, and *Le opere dei discepoli di Galileo Galilei*. Volume Primo. *L' Accademia del Cimento*. Parte Prima, ed. Pietro Pagnini, Florence, Giunti, 1942, pp. 21–22.

Fig. 1.8.
Borelli's table V, fig. 11
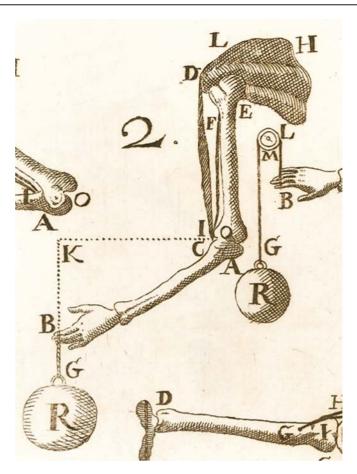
(1980), Keele points out[25] that the complex mechanism of the woodpecker's tongue, on which Leonardo intended to write,[26] is first explained by Ulisse Aldrovandi and again by Lorenzo Bellini and by Borelli, who gives a beautiful illustration of it in plate V, fig. 11 (Fig. 1.8).[27] Finally, Leonardo's extensive and innovative studies on mechanics

[25] Kenneth D. Keele and Carlo Pedretti, 1979/80, *Corpus of the Anatomical Studies in the Collection of Her Majesty the Queen at Windsor Castle*, London and New York, Johnson Reprint Corporation (3 vols.), vol. I, p. 362. For other aspects of Borelli's biological studies in relation Leonardo's, see F. S. Bodenheimer, "Leonard de Vinci, biologiste", in *Lènard de Vinci et l'espèience scientifique aux XVIe siècle*, Paris, Presses Universitaires de France, 1953, pp. 172–188, in particular p. 175 (flight of birds), 179 (Leonardo's studies on animal locomotion as compared with Borelli's principles of "iatophysics", i.e. the application of physics to medicine), 182 (Leonardo as precursor of Malpighi, Redi and Borelli). Cf. in the same volume the "Rapport final" by Alexandre Koyrè (p. 244).
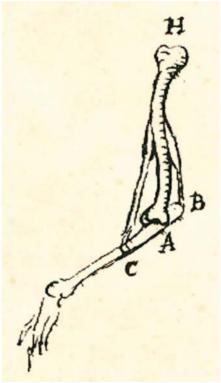
[26] Cfr. Windsor, RL 19070 v: "scrivi la lingua del pichio." See also Windsor, RL 19115 r: "fa il moto della lingua del picchio."
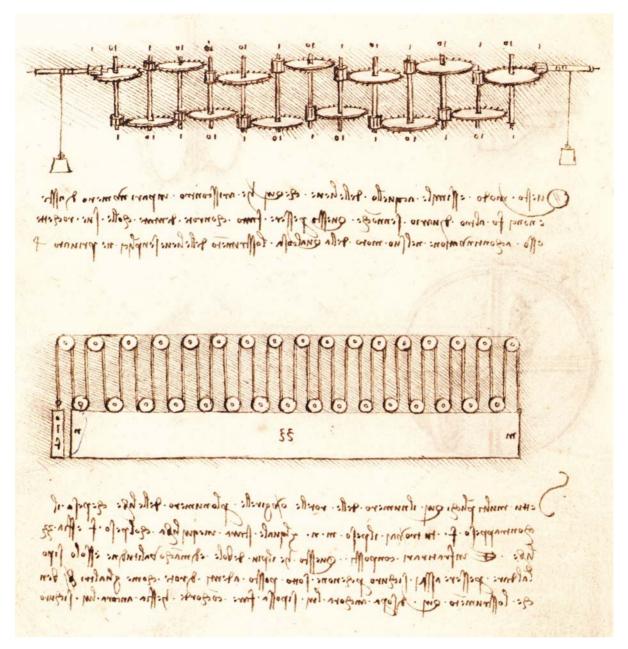
[27] Cfr. Guglielmo Bilancioni, "Leonardo da Vinci e la lingua del picchio," in *Rivista di storia delle scienze mediche e naturali*, XVII, 1926, pp. 1–12. Bilancioni does not mention Borelli, but for the explanation of the mechanism of the woodpecker's tongue he gives full credit to Borelli's pupil Lorenzo Bellini. The illustration in pl. V, fig. 11 (Fig. 9) is not based on that given by Ulisse Aldrovandi, *Ornithologiae* …, Bolgna, 1599, p. 838. According to Carlo Pedretti (oral communication), the way the complex mechanism of the bird's tongue is shown in an overall view of the bird's head, as seen three quarters to the right from above, is well in keeping with the type and character of Leonardo's anatomical illustrations of c. 1510 (e.g. the sheet with studies of the palate, tongue and larynx, and hyoid bone, in Windsor, RL 19002 r (A. 3)).

Fig. 1.9.
Borelli reference letters on
table III, fig. 2, H, C, and A

Fig. 1.10.
Codex Urbinas, f. 120 v

are shown by Roberto Marcolongo in 1939 to find reflections only in Borelli's work of nearly two centuries later.[28] Unfortunately, this interesting pointer was not followed-up by Arturo Uccelli (1940) in his monumental edition of those studies.[29]
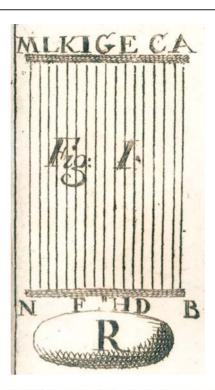
Of the eighteen plates in Borelli's *De motu animalium,* almost every one offers a figure that is similar in theme or style to Leonardo's. This is the case not only with drawings; coincidentally, several reference letters match. For example, the Borelli reference letters on plate III, fig. 2, H, C, and A (Fig. 1.9) match those of Codex Urbinas, f. 120 v (Fig. 1.10). Interestingly, Borelli appears to follow the sequence of illustrations in Madrid MS I: he starts with a figure that has elements in common with the page

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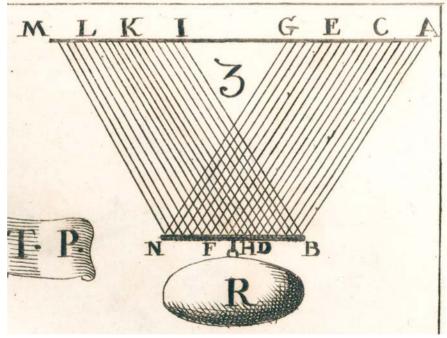
[28] Roberto Marcolongo, *Leonardo artista-scienziato*, Milan, Hoepli, 1939, pp. 197 and 294.
[29] Leonardo da Vinci, *I libri di meccanica nella ricostruzione ordinate da* Arturo Uccelli, Hoepli, Milan, 1940.
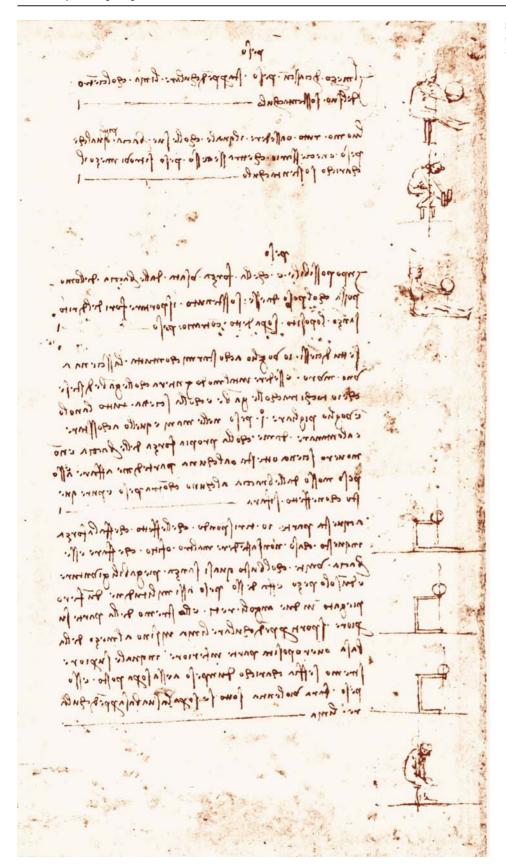
Fig. 1.12.
Borelli's table I, fig. 1

Fig. 1.13.
Borelli's table I, fig. 3
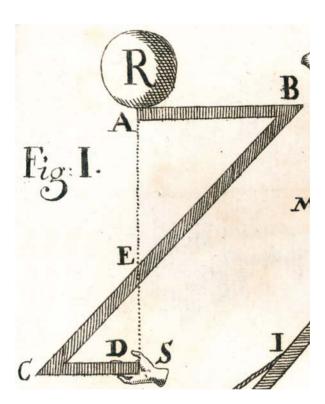
before the first section of missing pages in Madrid MS I. On Madrid MS I, f. 36 r (Fig. 1.11), Leonardo shows a block-and-tackle design with seventeen pulleys the same number as the number of muscle fibers in Borelli's first illustration on plate I, fig. 1 (Fig. 1.12). Plate I, fig. 3 (Fig. 1.13), has thirtyfour muscle fibers the same as the number of cable convolutions in Madrid MS I, f. 36 r. Indeed, the number seventeen shows up throughout the machine design folios of Madrid MS I in the number of pulleys and gear teeth. Is Leonardo trying to tell us something? Is he carefully maintaining analogs to his lost human muscle diagrams?
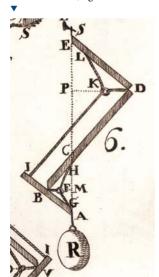
Leonardo's biomechanics can be interpreted through the comparative study of Borelli. Because of the great similarity of theme and organization, Borelli may have used it as an aid in interpreting drawings such as CA, f. 349 r-b [966 r] (Fig. 1.14), which represent the human body schematically, and are similar to the diagrams in Borelli's plate V, fig. 1 (Fig. 1.15). Madrid MS I, f. 90 r-v (Fig. 1.16) bears a striking resemblance to Borelli's plate V, fig. 6 (Fig. 1.17). This relates to the leg's lifting capacity
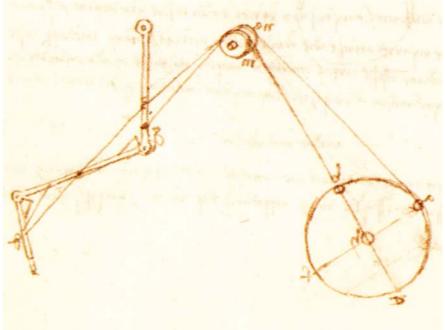
Fig. 1.15.
Borelli's table V, fig. 1
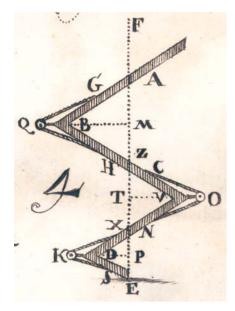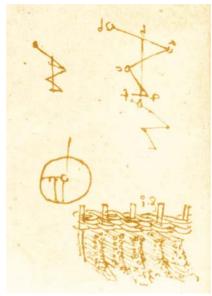
Fig. 1.16.
Madrid MS I, f. 90 v. Leg study

Fig. 1.17.
Borelli's table V, fig. 6
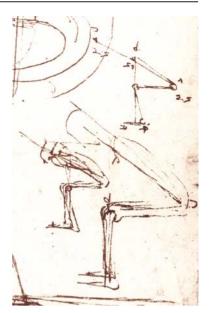
Fig. 1.18. Borelli's table XII, fig. 4

Fig. 1.19. Leonardo's MS L, f. 28 v

Fig. 1.20. CA, f. 164 r-a [444 r]

in retraction. Also in Borelli's plate XII, fig. 4 (Fig. 1.18), we see a graphic similarity to Leonardo's MS L, f. 28 v (Fig. 1.19), and CA, f. 164 r-a [444 r] (Fig. 1.20), showing a centerline though the body's limbs. In Paris MS L and CA, f. 164 r-a [444 r], are comparable diagrams of the forces involved in pulling a weight uphill which show a leg extending and retracting. This notation may date from 1497–1500. See Chapter III for Leonardo's Robot Knight's leg which may be the practical demonstrate piece based directly on these theoretical studies.

The seed of Leonardo's biomechanics was to come to full fruition nearly two centuries later with Giovanni Borelli's *De motu animalium*. Zubov appropriately refers to Leonardo as Borelli's "spiritual father."[30] Curiously, Pierre Duhem, a fervent advocate of the theory that much of Leonardo's legacy was indeed available and taken advantage of, by his successors, never mentions Borelli.[31] That Borelli learned from Leonardo may never be proved. But it seemed too much of a coincidence that his approach to biomechanics should be so strikingly similar to Leonardo's.

Rushing to my phone, I called Carlo Pedretti in the evening, and excitedly explained my theory.

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[30] Zubov, op. cit. (as in note 17 above), p. 184.
[31] Pierre Duhem, *Ètudes sur Leonard de Vinci. Ceux qu' it a lus et ceux qui l'ont lu*, Paris, A. Hermann, 1906, 1909 and 1913, 3 vols.

Leonardo's Programmable Automaton and Lion

These schemes [i.e. blue-prints] which have provided the basis for our reconstruction of Leonardo's car, along with the hypotheses that one may speculate about, confirm our conviction that this vehicle could never function the way it was designed by Leonardo.

Giovanni Canestrini, *Leonardo costruttore di macchine e di veicoli*, Roma-Milano, Tumminelli & C. Editori 1939, p. 128

My discovery that one of the leg diagrams in Giovanni Alfonso Borelli's *De Motu Animaliam* was the same as in Madrid MS I had Carlo Pedretti diving into his library as the realization set in that perhaps the missing material had been discovered at last. There had been a controversy when Madrid MS I was discovered in the 1960s about when the missing material may have been removed. Interviews were made and the case closed.[1]

And then if Leonardo's Book of Mechanics featured the similarity of man to machine, it is logical that he took it one step further—to automata that mimic the very motion and movement of life itself.

Leonardo developed a means of locomotion and control for automata which would later become common in the festivals and court masques of the sixteenth and seventeenth centuries. In 1478, while under the patronage of the Medici, he designed a programmable, mechanical computer-controlled automaton. This automaton was a precursor to mobile robots and was perhaps the earliest "computer" in western civilization. By reinterpreting material form Leonardo's notebooks, as well as the work of Japanese artisans of the eighteenth century, I was able to reconstruct Leonardo's intentions for the programmable automaton. This basic design may have been recycled by Leonardo in France some thirty-six years later for use as a platform for a self-propelled mechanical lion, again under a commission from the Medici. This has been ascertained only recently by Carlo Pedretti. Michelangelo Buonarroti the Younger, nephew of Leonardo's great rival, recorded the spectacle he witnessed at the wedding in 1600 of Maria de' Medici, Queen of France and Navarre, to Henry IV son of Antoine de Bourbon and Jeanne d' Albret. He was the first of the Bourbon Kings of France. In a booklet published in Florence in 1600, Michelangelo the Younger mentions an automaton that was presented at a banquet: a mechanical lion that walked a few steps and then rose on its hindquarters, opening its breast to show that it was full of fleurs-de-lis, a concept, concludes the younger Michelangelo, "similar to that which Leonardo da Vinci realized for the Florentine Nation on the occasion of Francis I's triumphal entry into Lyons" in 1515.[2]

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[1] See the section on "News and Notes" in *Renaissance Quarterly*, New York, Renaissance Society of America, XXIV, no. 3, autumn 1971, pp. 430–431, for the "Notice" signed by the members of a committee—Theodore S. Beardsley, Jr. (Hispanic Society of America), Carlo Pedretti (UCLA), and Paul Oskar Kristeller (Columbia U), Chairman—charged by the Renaissance Society of America "to investigate the circumstances under which two Leonardo manuscripts entitled *Tratados de fortificación, mecanica y geometria* had been recently discovered in the Biblioteca Nacional in Madrid".

[2] Nothing is left of Leonardo's project for the mechanical lion and what used to be known of it was only through the mentions by Vasari and Lomazzo, who did not indicate the precise occasion of the event nor its symbolism. The missing information is supplied by the *Descrizione delle felicissime nozze della Cristianissima Maesta' di Madama Maria Medici Regina di Francia e di Navarra* by Michelangelo Buonarroti the Younger (Florence, Giorgio Marescotti, 1600), p. 10, as first discussed and reproduced by Pedretti, *Leonardo architetto,* cit., p. 322. See also, by the same author, "Leonardo at Lyon," in *Raccolta Vinciana, XIX,* 1962, pp. 267–272, and *Leonardo. A Study in Chronology and Style*, London, Thames & Hudson, *and* Berkeley and Los Angeles, University of California Press, 1973 (second edition, New York, Johnson Reprint Corporation, 1982), p. 172.

The occasion of the earlier spectacle was described in Lomazzo's 1584 retrospective account of the allegory of friendship between the Medici and Francis I, which occurred at the latter's accession to the throne of France. Lomazzo writes that "once in front of Francis I, King of France, [Leonardo] caused a lion, constructed with marvelous artifice, to walk from its place in a room and then stop, opening its breast which was full of lilies and different flowers."[3] The Lion was an old symbol of Florence, and the lilies referred to the *fleur-de-lis* that Louis XI of France had given to Florence as a token of friendship. The two powerful families were combined symbolically in a dramatic presentation by one fantastic machine. Figure 2.1 shows my recreation utilizing the automaton presented in this chapter with a Lion shell over it.

Scholars offered no explanation for how Leonardo's lion walked. Carlo Pedretti felt that it would have been an anatomically correct approach. However, supplying the power required for actually walking, even in the twenty-first century, is a daunting task. In general, Renaissance Italian scholars have tended to under-rate the abilities of the court "special effects" people of the fifteenth to sixteenth centuries, perhaps, in part, because they tend to be non-technical, but also because it challenges the idea that Renaissance engineers were not as sophisticated as we.

There have been a number of books claiming to collect Leonardo's mechanical studies.[4] All have missed the overriding patterns, to say nothing of the complex devices. They concentrate on the clearly illustrated mechanical elements which are often reproduced in museums. The pulleys, bearings and gears along with some locks, weight lifting devices and other components or simple machines that would have been considered unremarkable by Leonardo's contemporaries. What is being reconstructed here is a much broader richer tapestry with far more complex mechanisms than previously known.

Fig. 2.1. Leonardo's Lion

Pieces of the Puzzle
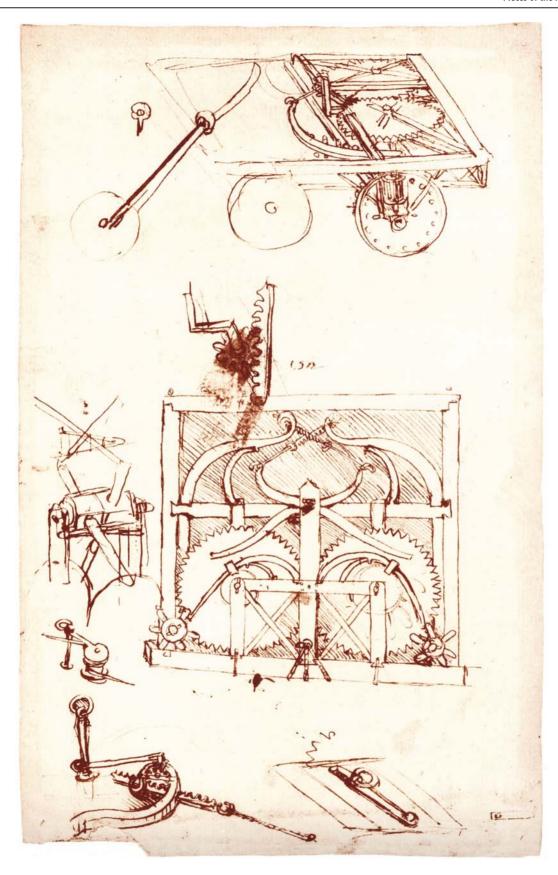
My reconstruction of Leonardo's programmable cart began in 1999 when I was invited to give the keynote speech at the 40th annual *Biblioteca Leonardiana* in Vinci, Italy, the town of Leonardo's birth. An honor usually bestowed on professors and scholars, the invitation came with a serious drawback: I would be asked to deliver the speech in Italian. Thus forewarned, I began a crash course in Italian at Hamline University. My first university class in perhaps 15 years started at 8:00 A.M. (very early for this night owl) and met three times a week. There I found myself sitting with teens and early twenty-somethings, a few of whom would show up for class in their pajamas.

Meanwhile, I had to think of a topic for the lecture, a problem that, compared to the prospect of carrying on in Italian for hours on end, seemed a bit more manageable. Codex Atlanticus,[5] f. 296 v-a [812 r] (Fig. 2.2) shows the formation of a technological idea as early as c. 1478, when Leonardo was about twenty-six years old. Since 1929, when it was first recognized by Guido Semenza as a self-propelled vehicle, the machine represented there has convinced all interpreters that the arbalest springs

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[3] Carlo Pedretti, *Leonardo architetto*, cit., p. 209, and, by the same author, "Leonardo at Lyon," in *Raccolta Vinciana*, XIX, 1962, pp. 267–272.

[4] Ivor B. Hart, The Mechanical Investigations of Leonardo da Vinci, London, Chapman & Hall, 1925. Arturo Uccelli, Leonardo da Vinci's Libri di Meccanica, Milan, Hoepli, 1940. Zur Mechanik Leonardo da Vincis (Hebelgesetz, Rolle, Tragfähigkeit von Ständern und Trägern). Inaugural Dissertation …. Fritz Schuster. Germany, K. B. Hof- und Univ.-Buchdruckerei von Junge & Sohn, 1915.

[5] Henceforth cited as CA.

Fig. 2.2. ▶
CA, f. 296 v-a [812 r]
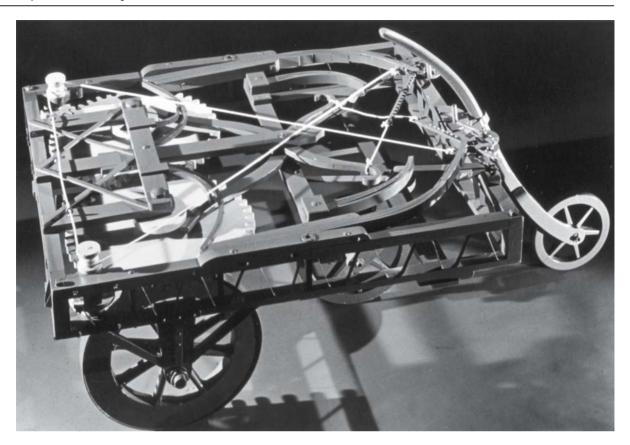
Fig. 2.3. Traditional reconstruction of Leonardo automaton

were the source of motive power (Fig. 2.3).[6] This way of reading Leonardo's technological graphic notation involved, of course, arbitrary alterations and modifications of his design, primarily the addition of cables transmitting power from the arbalest springs to the large gears. Scholars such as Giovanni Canestrini, Arturo Uccelli and Jotti da Badia Polesine argued and even quarreled over irrelevant points of details. All, however, praised Leonardo's ingenuity as the inventor of what they considered

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[6] Cf. Carlo Pedretti, *The Codex Atlanticus of Leonardo da Vinci. A Catalogue of Its Newly Restored Sheets*, New York, Johnson Reprint Corporation, 1978–1979, vol. II, pp. 125–126, new folio number 812 r. The studies on the subject are as follows (in chronological order): Guido Semenza, "L' automobile di Leonardo", in *Archeion,* IX, no. 1, 1928, pp. 98–104; Arturo Uccelli, "L' automobile a molle e Leonardo da Vinci", in *La lettura*, no. 3, March 1936, pp. 7–8; Id., "Leonardo e l' automobile", in *Raccolta Vinciana, XV–XVI*, 1935–1939, pp. 191–199; Giovanni Canestrini, *Leonardo costruttore di macchine e di veicoli*, Rome, 1939, in particular pp. 67–129 (section reprinted from the author's *L'automobile: il contributo italiano all' avvento dell' autoveicolo*, Roma-Milano, Tumminelli and C. Editori, 1939. See also the interpretation by another engineer, Enrico Gigli, later published in the book by Marialuisa Angiolillo, *Leonardo. Feste e teatri. Presentazione di Carlo Pedretti,* Naples, Società Editrice Napoletana, 1979, one page of text accompanying pl. 6. This too has arbitrary modifications to, or distortions of Leonardo's design, such that the resulting machine would never work.

The latest studies on the subject are as follows: Mario Loria, "Ruota trascinata e ruota motrice: L' "automobile" di Leonardo," in *Leonardo nella scienza e nella tecnica. Atti del Simposio internazionale di Storia della Scienza,* Firenze-Vinci, 23–26 giugno 1969, Florence, 1975, pp. 101–103; Augusto Marinoni, *Leonardo da Vinci: L' automobile e la bicicletta*, Milan, 1981, and, by the same author, "Leonardo's Impossible Machines," in *Leonardo da Vinci Engineer and Architect.* Edited by Paolo Galluzzi, Montreal, Montreal Museum of Fine Arts, 1987, pp. 111–130, in particular pp. 124–125. See finally my paper "Leonardo's Lost Robot," in Achademia Leonardi Vinci, IX, 1996 for the Appendix on pp. 109–110: "Leonardo's 'Automobile' and Hans Burgkmair's 'Gala Carriages'."

the first example of a differential gear.[7] It did not matter, therefore, whether the machine, as reconstructed by them for the Leonardo exhibition of 1939, would work or not. Like Leonardo's helicopter, this so-called "automobile" was just another idea for modern interpreters to integrate and develop. So did Canestrini as he prepared a set of blue-prints for the model presented in the 1939 exhibition. Inexplicably, he concluded that what he had so painstakingly reconstructed could never work:

> These schemes [i.e. blue-prints] which have provided the basis for our reconstruction of Leonardo's car, along with the hypotheses that one may speculate about, confirm our conviction that this vehicle could never function the way it was designed by Leonardo.[8]

In 1975 Carlo Pedretti became the first to recognize this drawing of "Leonardo's so-called automobile" in the *Codex Atlanticus* for what it is—an automaton—and theorized that the first major subsystem was a pair of large coil springs for propulsion.[9] My work built on this fundamental discovery. I would later discover that the automaton had nothing less than front-wheel drive and rack-and-pinion control. But it would require my reconstruction of several major missing subsystems, including the steering, programming, and escapement or "clock," to make a full reconstruction possible. Reinterpreted by me as representing a programmable automaton, this mechanism was to have a great impact on Leonardo's future views, ranging from biomechanics all the way to his achievements with the famous and now less enigmatic mechanical lion of about forty years later.

I had left in my last paper on Leonardo some tantalizing notes about this "car," and the hint had been picked up by Romano Nanni, director of the Biblioteca Leonardiana in Vinci, Italy, the birthplace of Leonardo. This was why I found myself invited to the 40th annual *Celebrazioni Leonardiae*. I chose the process of reconstructing the programmable automaton as my thesis.

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My struggle to learn Italian began with a sleepless night before the first class. Wishing very much for any other chore other than attending class at 8 A.M., I was happily surprised to find my teacher, Alessandra Matthys, to be a highly intelligent, attractive, bright eyed brunette from Rome. I would be learning from a native. In the course of the class, I also became friends with a Chinese music professor, Yalli Yu, who was taking the class to better serve her students for music study in Italy. Yalli and I became good friends and studied together at her office and over pizza. Loaded with books, flash cards, tapes, notebooks, and homemade index card notes held together with key rings, I would study day and night in coffee shops, restaurants and at my girlfriend's apartment. When studying with the audio tapes, I would occasionally give a hoot of joy when I got all my answers right. In spite of doing all the homework, I still had difficulty with tests (if only they would give me the entire day). But I gamely pressed on, offering some help from my worldly travels to my fellow students but in one embarrassing incident offering completely incorrect grammatical advice.

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[7] The interpretation of Leonardo's drawings as showing a differential gear is unfounded. A differential gear is a complex bevel gear mechanism designed to permit differential motion of a pair of drive wheels in order to accommodate fewer revolutions of the inside wheel versus the outside wheel during turning. The two front wheels of the platform for automaton rotate together at a constant velocity.

[8] Canestrini, p. 128.

[9] Carlo Pedretti, "Eccetera: perchè la minestra si fredda" (Codice Arundel, fol. 245 recto). XV *Lettura Vinciana* …, Firenze, Giunti, 1975, p. 13, note 9, where the so-called "automobile" represented in CA, f. 296 v-a [812 r], is considered more likely "a cart for festivals moved by springs and planned to cover brief tracts as from one side of a piazza to another" ("non era altro che un carro per feste azionato da molle e destinato a percorrere brevi tragitti come da un punto a un altro di una piazza"). In his *Leonardo architetto* (Milan, 1978), pp. 319–322, the interpretation is further elaborated and the Leonardo drawings shown in relation to other early studies in the Codex Atlanticus at the Uffizi.

As the text of the paper would be prepared in Italian, I hired my teacher to translate the paper with Carlo's supervision. Iteration after iteration, I would pick up the latest draft from her mailbox and correct it, watching it slowly take shape. As my pronunciation improved, I would also practice the entire speech, complete with slide presentation, for a captive audience of friends, relatives and party guests at a class pot luck to which I brought my very un-Italian beef stew. The party was at my Italian teacher's house, a nineteenth-century brick home on the outskirts of downtown St. Paul where, to the consternation of my fellow students, I joined in to a rendition of "Volare" in which we were accompanied on the piano by the teaching assistant. The damage inflicted on those within earshot must have been devastating.

At this stage of my development as a book collector/addict, I was hunting mostly on the Web using search terms like "rare book dealer." This led to some interesting consequences. With the advent of the Web almost anyone with a basement full of books may become a rare book dealer. One benefit to the consumer is that sellers may be ignorant of the true value of the merchandise, as was the case with a Belgian dealer from whom I purchased the facsimiles of Leonardo's anatomical studies. The down side of dealing with those who don't know how to price is that they also don't know how to pack! In spite of instructions to double box, insure, etc., this individual sent my massive three volume set in a simple cardboard box, with predictable damage. This required a visit to the book binder Dennis Rude, my former book arts instructor, whose amusing asides, encyclopedic knowledge and passion for book restoration know no bounds. In a month he had the bumped and torn corners repaired, and I was able to insert them in the two armoires that house my collection of Leonardiana.

❖

Although they at first told me that delivering the paper in Italian was simply "how it was done," Carlo and his lovely wife Rossana began to sense my difficulty as the year went on. The enormity of mastering Italian in so short a time would have been difficult, even for a person gifted at languages, which I am not. My reading timed out at 45 minutes – painful even in my native language. My battle plan consisted of having my Italian teacher tape record the entire text in Italian so I could practice to my heart's content. As a further aid, I would then rewrite the entire text phonetically in Italian! Perhaps it was my numerous phone calls to Carlo and Rossana begging for help with my pronunciation that led to the final solution. They eventually took pity on me and pulled some strings so that I could give the paper in English with simultaneous translation. Cleverly, they gave the excuse that Italy, in joining the European Union, should reach out to non-Italians. And of course there was the new millennium, a great reason to extend mercy to poor Anglophones such as myself. It was only later that I learned that the Italian of a certain famous British Leonardo scholar was so poor that not a single person understood him! What a relief!

❖

As we've seen, automata of various descriptions were very much on Leonardo's mind up to and during the design of the programmable cart. However, the *Codex Atlanticus* and Uffizi drawings, which are the surviving record of the design, do not show Leonardo's complete intentions for the automaton. I would have to reconstruct it by reinterpreting other materials from Leonardo's oeuvre.

Armed with the critical guidance of Carlo that I was facing an automaton and not an unworkable anticipation of the modern automobile, I looked to robotic designs of subsequent centuries and diverse cultures to form my design and operation hypotheses for Leonardo's automaton. I then reinterpreted the fragments based on these hypotheses. My guess was that traces of the programmable automaton would be found in Renaissance accounts of ancient automata as well as in later designs by inventors who may have had access to Leonardo's oeuvre. This information would aid in inter-

preting and reconstructing the nuts and bolts of Leonardo's design as well as its performance characteristics and application. At the same time, I drew upon my lifelong experience as a student of Leonardo's legacy.

Although there are now no longer any complete designs for automata in Madrid MS I, that manuscript contains numerous examples of potential components, such as compact spring drives with imaginative integral fusee mechanisms that could have powered them. A fusee is a spiral-shaped drive device that compensates for a springs winding down. The typical fusee has a spiral groove wrapped with a chain or gut cord which is driven by the spring. As the spring winds down, the chain or gut drives the increasingly larger diameter fusee, thus compensating for the loss of torque. Leonardo's fusees are mounted on a drum, often referred to as the going barrel or tambour, in which is contained a spring. They are a unique geared design in which the fusees are mounted on the top of the barrel, which rotates and automatically compensates for the loss of torque as the spring unwinds. Various means are used to transfer the power from the moving fusee to a stationary rotating power output shaft. They have no specific designation as to application, and could well have been employed in mobile automata, where weight and size need to be optimal. These could have been used as power sources for successors of the programmable automaton.

Folio 4 recto of Madrid MS I shows the first of a series of ingenious, lightweight, compact fusee-regulated power supplies (Fig. 2.4, p. 28). Spiral arrays of driver pins connected to the barrel form the fusee. A sliding lantern gear transfers the barrel's rotation to the output. These gears allow greater amounts of torque to be transmitted than do conventional cables and chains. Madrid MS I, f. 16 r (Fig. 2.5, p. 29) shows a conical lantern gear to compensate for the difference between the pinion path and the fusee pins.

One of the things that makes it challenging to interpret Leonardo's drawings is that the pages in the Codices are not always bound in a way that allows the reader to make sense of them easily. Whether Leonardo did this deliberately, as he did with his famous mirror-writing, or if this is the result of the pages' being bundled together as he roughly organized his notes into books, or of their being assembled arbitrarily from files by later, less caring hands, the result has been to mislead and confuse investigators for hundreds of years and to create work for scholars who want to "get back to zero" when the notes were complete and made more sense. For example, the often-reproduced design on Madrid MS I, f. 45 r (Fig. 2.6, p. 30) has usually been interpreted as a power supply for a clock. But if the design is laid on its side, it could be read as constituting a drive element for an automaton. The disk of the output appears to be a drive wheel. All of these designs feature a significant gear ratio increase that would be useful for propulsion.

Several theoretical studies comparing the various spring morphologies for use as a power source appear in Madrid MS I, f. 85 r (Fig. 2.7, p. 31). The upper left corner of the page shows a "T"-shaped key used for winding. It is possible that a key like this was used to wind the programmable automaton. The depth of Leonardo's interest in springs is apparent: he even shows manufacturing techniques illustrating automated drawing machines for strips of steel in MS G, f. 70 v (Fig. 2.8, p. 32).[10]

Numerous gear studies, ranging from low-cost sheet metal gears to elaborate helical and involute gear forms, appear on these pages. Theoretical studies of gear geometry are also present. Cams in a myriad of forms are shown, beginning on Madrid MS I, f. 1 v and 24 r (Figs. 2.9 and 2.10, pp. 33 and 34) Leonardo engages the curved surfaces on the inside and outside, and mixes gears with cams to produce hybrids.

One would expect that such detailed studies would appear with other drawings showing the practical demonstrations of their use in sophisticated automata. But with the exception of an astronomical clock, such drawings do not appear in Madrid MS I.

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[10] See Ladislao Reti (ed.), *The Unknown Leonardo,* New York, Abradale Press, 1974, in particular the chapter by Silvio A. Bedini and Ladislao Reti, "Horology," pp. 240–263, with various kinds of springs discussed on pp. 250–253.

Fig. 2.4. Madrid MS I, f. 4 r
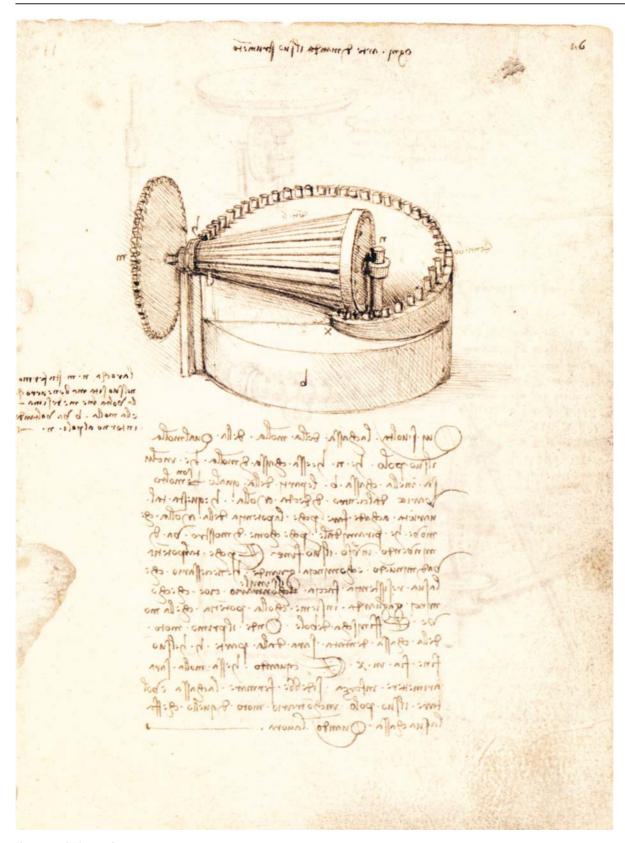
Fig. 2.5. Madrid MS I, f. 16 r

Fig. 2.6. Madrid MS I, f. 45 r

Fig. 2.7. Madrid MS I, f. 85 r. Spring morphologies for use as a power source
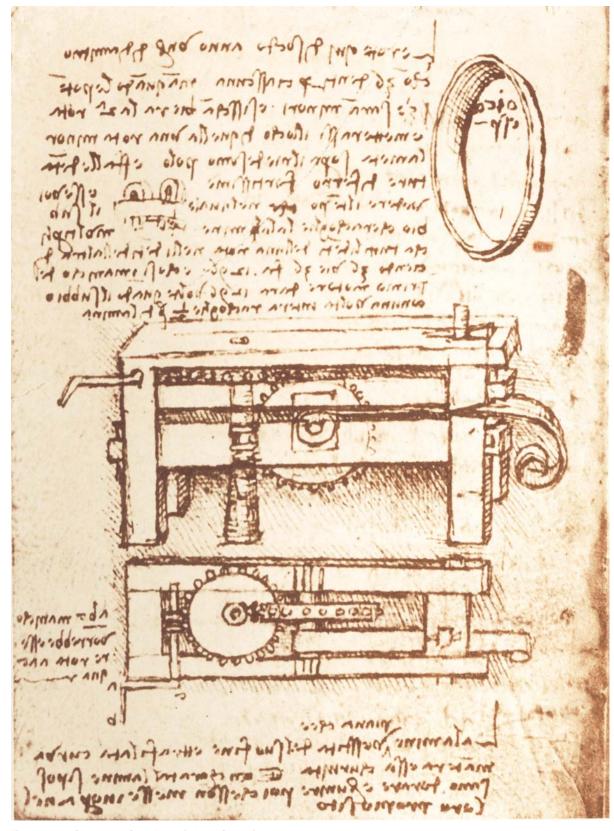
Fig. 2.8. MS G, f. 70 v. Manufacturing techniques for steel strips
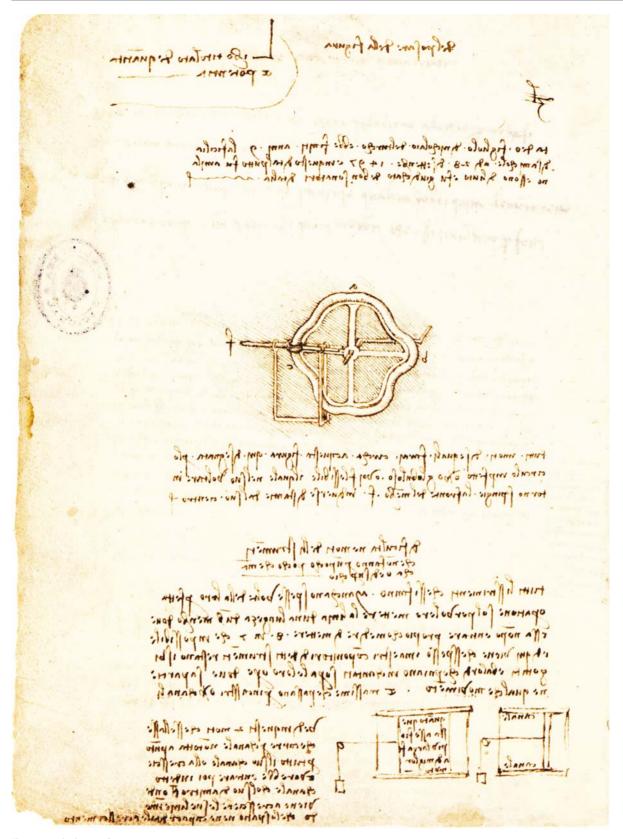
Fig. 2.9. Madrid MS I, f. 1 v
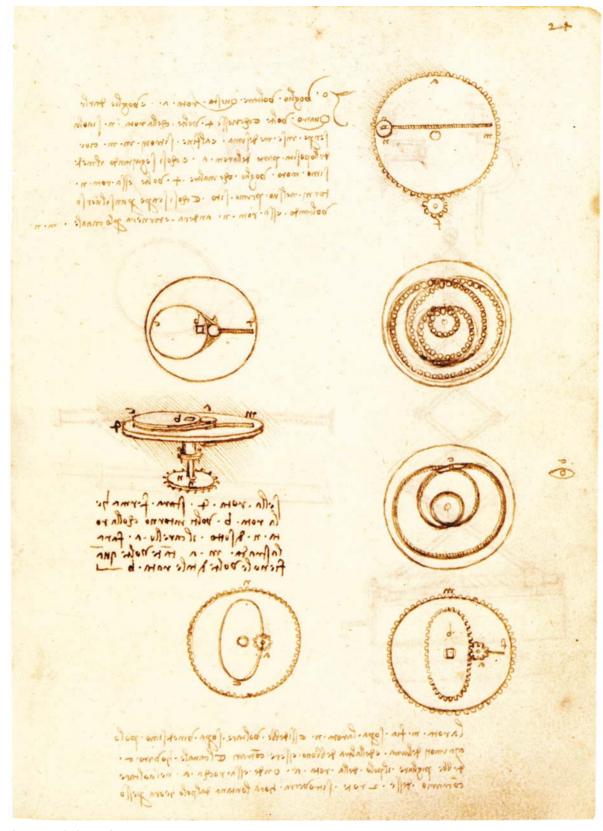
Fig. 2.10. Madrid MS I, f. 24 r

Fig. 2.11. Leonardo's family coat of arms

I suspect drawings showing complex automata were once part of the eight folios that were removed at some point in time before the Madrid codices were published. As shown in the Reti edition, they are ff. 37–42 and 55–56.[11]

If this is indeed the mechanism that supported the fabulous Robot Lion, the beast, which would have been supported by the base mechanism, may have been based on Leonardo's family coat of arms—an upright lion (Fig. 2.11).

The significance to Leonardo of seeing his name in heraldic form could hardly be understated. With his penchant for secret writing and similar arcana, I think Leonardo could hardly resist the opportunity to make a pun by employing an element of his name in his legendary Robot Lion.

Several seemingly unrelated pieces of evidence, when reinterpreted, reveal the intended working of Leonardo's programmable automaton, the first of which was the Robot Lion. The trail I followed began, strangely enough, with a late eighteenth-century Japanese "Karakuri," or tea carrier,[12] known to me from previous research. In this design, separated by several centuries and two continents from Leonardo, I found an autonomous mobile robot of equal complexity, construction, materials and performance characteristics as those of the lion that delivered flowers to Francis I.

The fourteen inch tall (35.56 cm) Tea Carrier (Fig. 2.12) has a cherry wood frame, and composite gears of laminated oak and Japanese cedar for strength held together by wooden pins. The only metal components are in the governor, which regulates a coiled baleen (whale-bone) spring and is steered by means of programmable cams mounted on the spring's hub. A cam follower actuates the front steering wheel.

Cams are revolving mechanical components, such as a wheel, so shaped as to impart a preprogrammed motion in another piece engaging it. By changing the shape of the cam, one changes the "program," the motion that is imparted to another piece engaging it. Seeing programmable cams in the Japanese design, I reexamined Leonardo's programmable automaton and saw that they were present there as well. I had discovered the programming system, the second major subsystem of Leonardo's cart.

But the Karakuri was not likely a native Japanese design, as attested to by the surviving Renaissance-era mobile automata that bear a striking resemblance to the Karakuri. These are the "Monk" and the "Cittern" Player. Both are propelled by wheels, are spring wound and have simulated feet that "walk," powered by the action of the clockwork. The Monk is programmed to move in a two foot wide square. Some scholars think the Monk could have been built by Juanelo Turriano, master watchmaker in the service of Charles V. But how did such a design find its way to eighteenth-century Japan, and how might it be connected to Leonardo's Madrid Codices? Although I had a perfect model for how Leonardo's automaton worked, I would not be able to connect it to the master unless I could establish the path it took to reach Japan.

Given the growing trade between Japan and the West during this period, I hypothesized that the Tea Carrier's programmable cams were modeled on Spanish designs— designs that themselves may have been inspired by Leonardo's Madrid Codices, for Madrid MS I and MS II were kept in Spain since their transfer to the royal library in

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[11] Leonardo da Vinci, *The Madrid Codices*, vol. III, Commentary by Ladislao Reti, New York, McGraw-Hill, 1974, pp. 23–26. According to Carlo Pedretti, cit. in Chapter I, note 1, p. 322, those missing sheets could well have contained "most accurate and spectacular studies for the robot."

[12] This is fully discussed and illustrated in my book *Robot Evolution: The Development of Anthrobotics*, New York, Wiley, 1994, pp. 27–29.
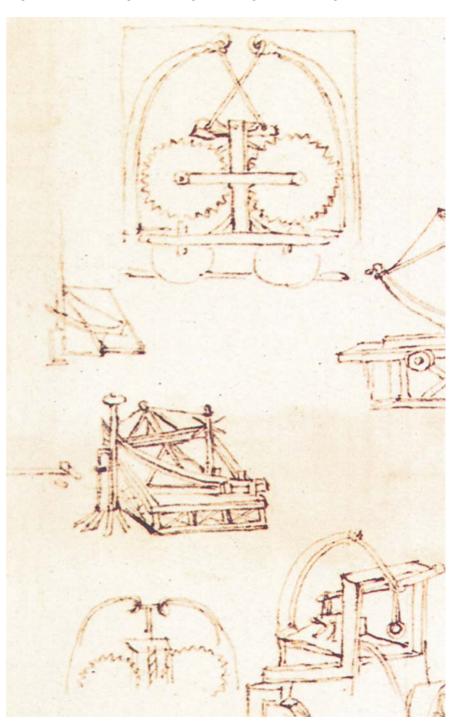
1642. The missing section of the first manuscript, unknown to us today, could itself have disseminated Leonardo's ideas. Autonomous robot designs do appear in Spain at this time in the work of Juanelo Torriano. Such designs became increasingly common in the eighteenth century, with the development of water-powered grottos and spring-driven dining table servers. The design for the Tea-Carrier closely resembles that of the "Monk" (c. 1560), an automaton figure which is programmed to move in a square and which is attributed to South Germany or Spain.[13] This technology may have been transferred to Japan by Spanish Jesuit missionaries during the eighteenth century, where it was reinterpreted as a geisha. I reasoned this from my research into early automata for my book *Robot Evolution*. I saw the similarity and noted that one way the Jesuits won favors (and converts) was to gift foreign leaders with clocks, novel devices that were highly prized. This is how one of the Jacquet Droz draftsmen got to be located in China.[14]

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[13] Maurice and Mayr, *Clockwork Universe*, New York, Smithsonian, 1980, p. 170.
[14] Alfred Chapuis and Edmond Droz, *Automata a Historical and Technological Study*, London, B. T. Batsford Ltd., 1958, pp. 300–302.

Another piece of the puzzle, the escapement, came from part of an early sixteenth century of Leonardo drawings, Uffizi, GDS, no. 4085 A r (Fig. 2.13). This is a large sheet of technological drawings, including manufacturing.[15]

Fig. 2.13.
Uffizi, GDS, no. 4085 A r.
Technological drawings

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[15] Reproduced in facsimile in *I Disegni di Leonardo da Vinci e della sua Cerchia nel Gabinetto dei Disegni e Stampe della Galleria degli Uffizi a Firenze ordinati e presentati da* Carlo Pedretti. *Catalogo di* Gigetta Dalli Regoli, Florence, Giunti 1985, pp. 92–93, no. 43 [4084A]. See also my paper on "Leonardo's Lost Robot," (as in note 6 above), p. 109, fig. 32.

The top and bottom far left figures clearly show a similarity to the plan view of CA, f. 296 v-a [812 r] (Fig. 2.14)—that is, they are of a mechanism having two large gears and arbalest springs. An arbalest spring is simply a strip of metal, wood, horn or other springy material that can be bent to store and release mechanical energy. Although the form taken here is different—a rocker arm acting on the two separate gears to form an escapement—the basic concept is the same. An escapement is a mechanical device that releases energy from a spring in an incremental and controlled manner. In this mechanism, a rocker arm, held in tension by cables connected to the arbalest springs, creates an escapement to regulate the speed of the gears. The
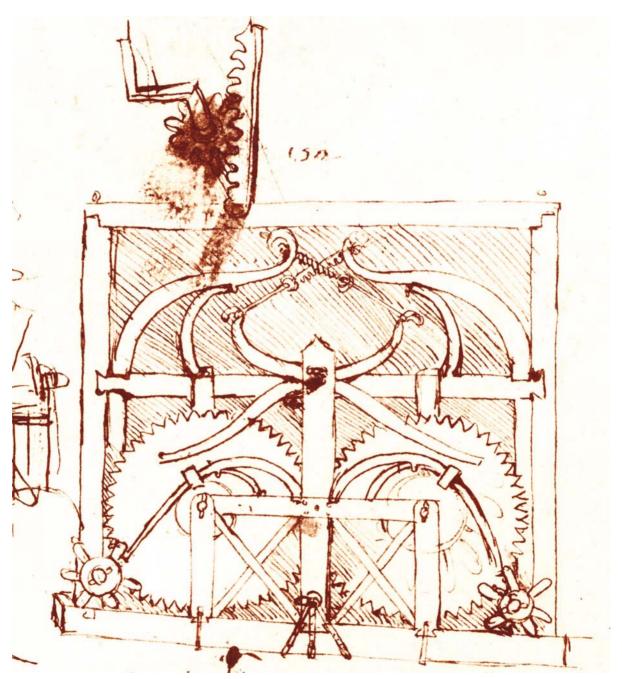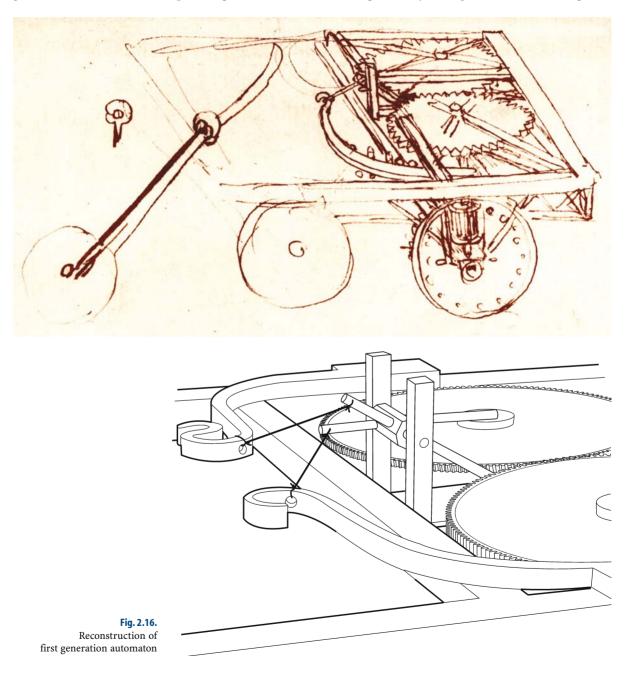
Fig. 2.14. Plan view of CA, f. 296 v-a [812 r]

rocker oscillates back and forth like a teeter-totter alternatively engaging and disengaging the gear teeth. Two wheels located on the bottom of the machine could be for locomotion, although it is difficult to interpret them at this time.

It was this element, the escapement acting on the barrel gears, which confirmed what I had already suspected—that the arbalest springs engaging the cogs comprised an escapement mechanism. And if this were indeed an escapement mechanism, all the cables, differentials and details imagined by scholars would fall away, revealing not Leonardo's primitive striving toward an automobile but rather his fully developed design for a working automaton. I was on the road to discovering the third major subsystem of the Leonardo cart—the escapement or "clock."

Only recently have I discovered that the above machine is also related to the top perspective figure of CA, 296 v-a [812 r] (Fig. 2.15). My reinterpretation is shown in Fig. 2.16.

Fig. 2.15. CA, f. 296 v-a [812 r]. First generation automaton

Fig. 2.16.
Reconstruction of first generation automaton

Indeed, this reinterpretation and the Uffizi sheets show how critical to Leonardo the escapement was. I now see this figure as a distinct, different design than the one shown below in plan view. It's main focus being the escapement the drivetrains most critical component.

Also, in a recent reinterpretation, I discovered that the left of center detail of CA, f. 296 v-a [812 r] (Fig. 2.17) relates to an escapement mechanism similar to the one depicted in the Uffizi GDS, no. 4085 sheet. Figure 2.18 illustrates my reconstruction. A split (to adjust phasing) pair of pallets on a common pivot alternatively engage and disengage the pair of large gears.

But it was far from clear to me how the escapement worked in the plan view. Was it completely shown in CA, f. 296 v-a [812 r], or was part of it shown in the Uffizi GDS, no. 446 E-r drawing? I explored using the Uffizi escapement combined with the plan view and made some pretty drawings—but were they correct? How did it connect to the drive wheel and how were they connected to the springs? I was missing bottom and side views and had only a plan view and fragments to work with. However, I had at least a theory of the two basic subsystems: Carlo's coil springs and my computer-like cam system.

I was ready to begin the reconstruction.
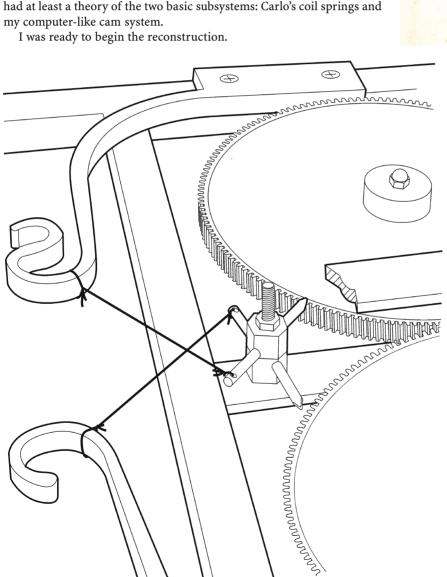
▲
Fig. 2.17. CA, f. 296 v-a [812 r]. Escapement mechanism detail

Fig. 2.18.
Escapement reconstruction

Reconstruction

The programmable automaton as depicted in the *Codex Atlanticus* consists of a square mortised and dovetailed wooden frame approximately 20 by 20 inches (50.8 by 50.8 cm). I base these dimensions on several measurements taken from the *Codex Atlanticus* drawings, which I believe are full-size preliminary fabrication drawings,[16] not scaled drawings. In other words, in Leonardo's time, standardized measurements small enough for mechanisms did not exist. Producing full-sized drawings provided a simple, accurate and direct guide for the craftsman who would build the mechanism. The craftsman would transfer the design directly form the drawings to the workpiece. If we assume that the dimensions of the automaton are full-size, we discover that they provide a perfect stage on which to mount a figure such as a life-sized lion seated in an upright posture, but would seem small for a lion walking on all fours, as would have been necessary for the revelation of the flowers at Francis I's entry into Lyons in 1515.

The frames contain two interdependent subsystems for propulsion and guidance. Leonardo also went to pains to secure the joints with fasteners, no doubt for increased ruggedness. In the top perspective view, a second, lower frame is attached to the top via angled brackets.

Using the plan figure as a guide, I concluded that the right side is for steering. This is indicated by the presence of several cams drawn on the barrel gear of the right side unit. The left-hand unit cam follower return spring has a screw which may be tightened with a nut, as shown in CA, f. 320 v-a [878 v] (Fig. 2.19).
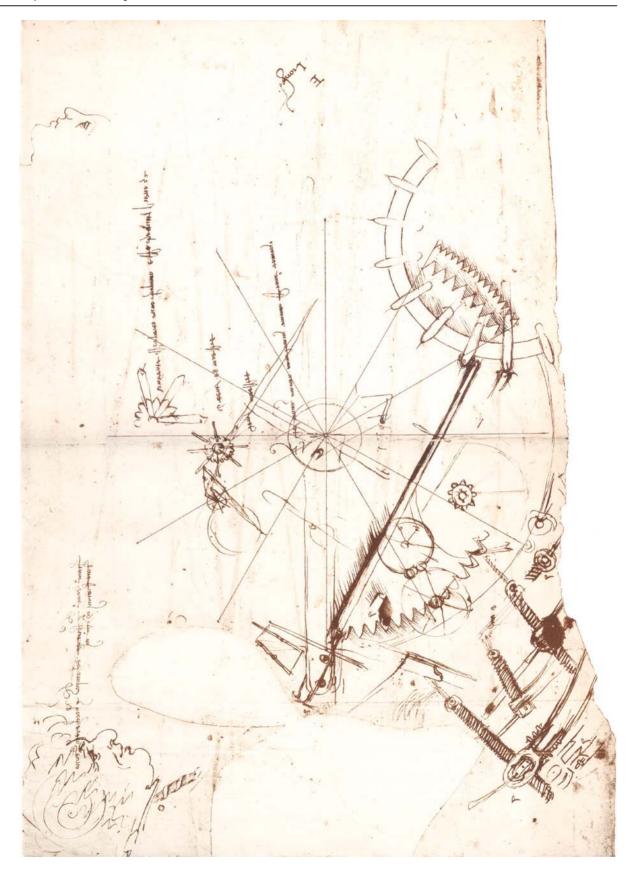
This arrangement suggests the left-side unit is for propulsion. Controlling the tension of the cam followers is the means of controlling their speed. It seemed to be supported by Leonardo's choice to illustrate the left side of the automaton in his perspective sketch in CA, f. 296 v-a [812 r] (Fig. 2.15) which I thought at the time showed a rough idea for propulsion.

The two large barrel gears mesh together doubling the available power (Fig. 2.14). The interaction of the two corner cogs form a complete escapement that enables speed regulation of the large springs and hence the large gears. The gear ratio from the springs to the spoked drive wheels increases the springs' revolutions per minute to maximize the travel of the programmable automaton.

Petal-like cams located on the top surface of the large gears drive the two scissors-like cam followers, which are kept in contact with the cams via the arbalest return springs. These springs have traditionally been mistaken for a power source, but I now saw they are actually return springs for the cam followers, and probably would have been fashioned out of bent wood, bamboo, horn, or even bone perhaps ribs. This material is likely because large amounts of force are not needed to keep the cam followers in contact with the cams. Too much force would create friction and drain the springs' power.

The top perspective sketch CA, f. 296 v-a [812 r] is a separate distinct design as mentioned above, and Leonardo seems to be exploring two steering options. The

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[16] A scale drawing, or at least a drawing begun as such and then turned into a rough sketch, is shown on CA, f. 320 v-a [878 r], c. 1478, which I consider as part of the studies for the programmable automaton. As in other sheets (e.g. CA, f. 347 r-b [956 r]), the wheels are shown with a 4.2-inch (106 mm) radius. Leonardo's drafting procedures are shown by the draft of a letter to his patron Giuliano de' Medici with which, about 1515, he was to complain about the behavior of one of his two German assistants, who was apparently prepared to steal his inventions. See CA, f. 247 v-b [671 r], Richter, §1315: "Afterwards he wanted to have the models made in wood, just as they were to be in iron, and wished to take them away to his own country. But this I refused him, telling him that I would give him, in drawing, the breadth, length, height, and form of what he had to do; and so we remained in ill will." Cf. Carlo Pedretti, Introduction to *Leonardo da Vinci Engineer and Architect*, (as in note 6), pp. 12–13, and *Achademia Leonardi Vinci, VI.* Firenze, Giunti, 1993, p. 184.

first looks like a tiller connected to the wheel with the opposite end driven by the linkage. Leonardo has a design dilemma with the escapement mechanism in the way it's difficult to attach a steering linkage to the tiller. The second seems to be a wheel mounted directly underneath the platform, with the fork's shaft passing up into the automaton mechanism. Mounting the steering wheel there solves the problem of interference with the escapement mechanism. This gave me clue that the steering wheel could connect to the upper cam follower arm.

The bottom three figures of CA, f. 296 v-a [812 r] relate to an additional control mechanisms (Fig. 2.2). The most detailed is a rack-and-pinion control mechanism (Fig. 2.20). In the center of CA, f. 296 v-a [812 r] directly above the main plan view, is a rack-and-pinion mechanism with the pinion axle terminating in a crank (Fig. 2.21). A rack is a toothed bar usually made of brass or steel. A pinion is a simple spur (toothed) gear. In this case, the teeth of the pinion mesh with those of the rack. This, I believe, is the pinion mounted in the left return spring shown in the bottom left hand corner of the folio. The spool and cable version above it is a simpler lower-cost alternative embodiment. The spool (Fig. 2.22) would clip into the cam follower, re-

Fig. 2.20.
CA, f. 296 v-a [812 r].
Rack-and-pinion control
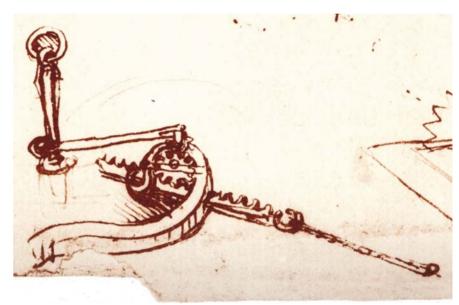
Fig. 2.21.
CA, f. 296 v-a [812 r].
Rack-and-pinion with crank
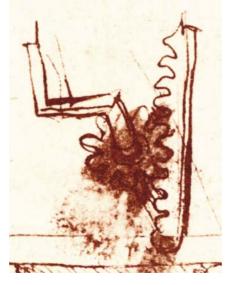
Fig. 2.22. CA, f. 296 v-a [812 r]. Spool with cable

placing the gear (Fig. 2.23). Based on the lower left figure, this subassembly is mounted on the upper left return spring. This is the reverse location of the rack in the top view which is near the right return spring. Two functions could be accomplished with this arrangement. First, the automaton could be slowed as it encountered resistance of a dedicated cam. Secondly, upon slowing, the rack-and-pinion mechanism could trigger a special effect, such as opening a door.
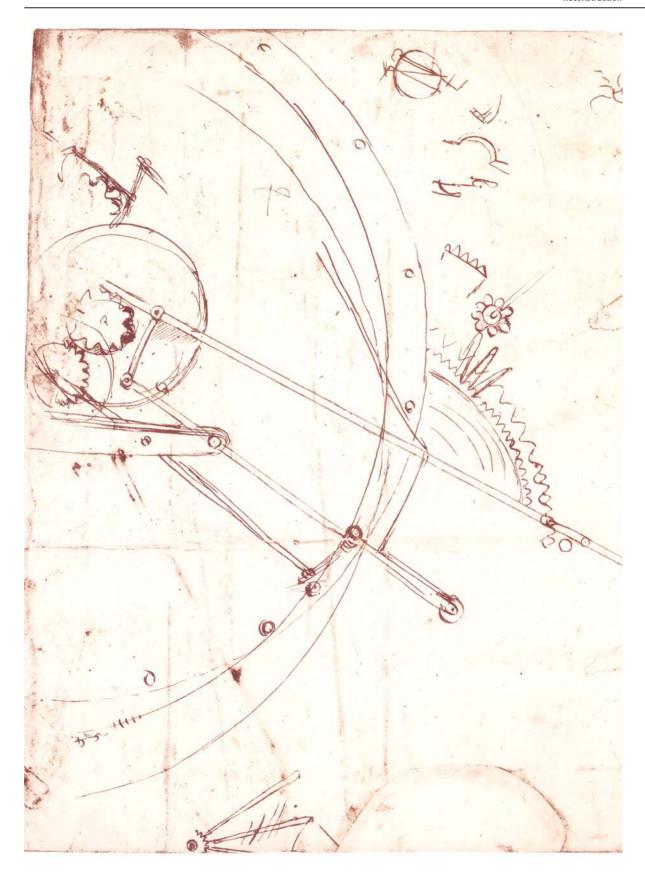
Following the action of the escapement and drive train I could see it has front-wheel drive! Both spoked wheels are driven under power; this interpretation is based on the escapement arbalest springs bias in relationship to the corner cogs caused by the gear hubs creating a ratchet (a single direction gear-train). Through Carlo Pedretti's insight that the leaf springs could not produce enough revolutions per minute to make the platform move a useful distance albeit that he did not understand their alternative function and by using the Japanese Tea Carrier as a model, I am now convinced that Pedretti was right in suspecting that there are large coil springs located below the large gears.[17] I suggest that a group of slight arcs, shown within a figure on the bottom center of CA, f. 320 r-a [878 r] (Figs. 2.24 and 2.25) may represent just such a spring within a barrel gear. Power for the automaton would have come from winding it up like a giant toy, perhaps by one of the corner cogs, so as to take advantage of the gear reduction. The force generated by these springs would be substantial, perhaps in the fractional horsepower range.
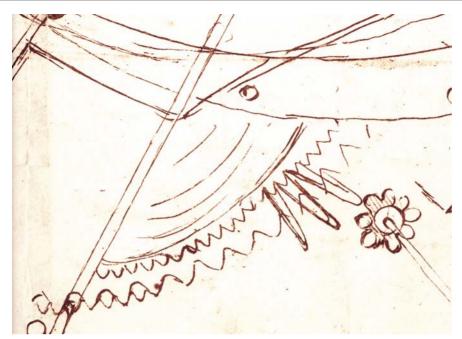
A second level of gearing of the going barrel gear appears on both the lower right of CA, f. 320 r-a [878 r] and CA, f. 320 v-a [878 v] (Figs. 2.19 and 2.24). This second level of gearing may represent an alternative and possibly earlier embodiment. In addition, there is a parallelogram linkage shown in smaller preliminary sketches at the center left of CA, f. 320 r-a [878 r]. This folio also provides an important reconstruction detail—the right corner cog and its smaller pinion gear meshing with the large barrel gear. I then reasoned that the lantern gear shown in the top of CA, f. 296 v-a [812 r] must be attached to the same vertical shaft powering the drive wheel pegs. This provided me with the vital clue to see below the plan view and solve the mystery of the drivetrain.

Fig. 2.23. Reconstruction of spool and cable

[17] This was already discussed in the Appendix to my paper "Leonardo's Lost Robot," (as in note 6 above), p. 109, note 7. Carlo Pedretti has shown that a comparable application of a coil spring is found in Leonardo's so-called "helicopter" sketch. See his *Studi Vinciani*, Geneva, Droz, 1957, pp. 125–129, and his *Leonardo. The Machines*, (as in note 14 above), pp. 8–10 and 29. See also Giovanni P. Galdi, "Leonardo's Helicopter and Archimedes' Screw. The Principle of Action and Reaction," in *Achademia Leonardi Vinci,* IV, Firenze, Giunti, 1991, pp. 193–195.

Fig. 2.24. ▶
CA, f. 320 r-a [878 r].
Sketch of spring in barrel

Fig. 2.25.
CA, f. 320 r-a [878 r].
Detail of spring

Fig. 2.26.
Uffizi, GDS, no. 446 E-r
▼

Near the cut-out section of Uffizi, GDS, no. 446 E-r (Fig. 2.26) is another parallelogram mechanism similar to the one above it. These linkages may be indexing or escapement concepts. Finally, yet another secondary level of gearing is also shown on CA, f. 339 r-a [926 r] (Fig. 2.27) and CA, f. 347 r-b [956 r] (Fig. 2.28). I dismissed all of these as surplus in the search for the basic mechanism.
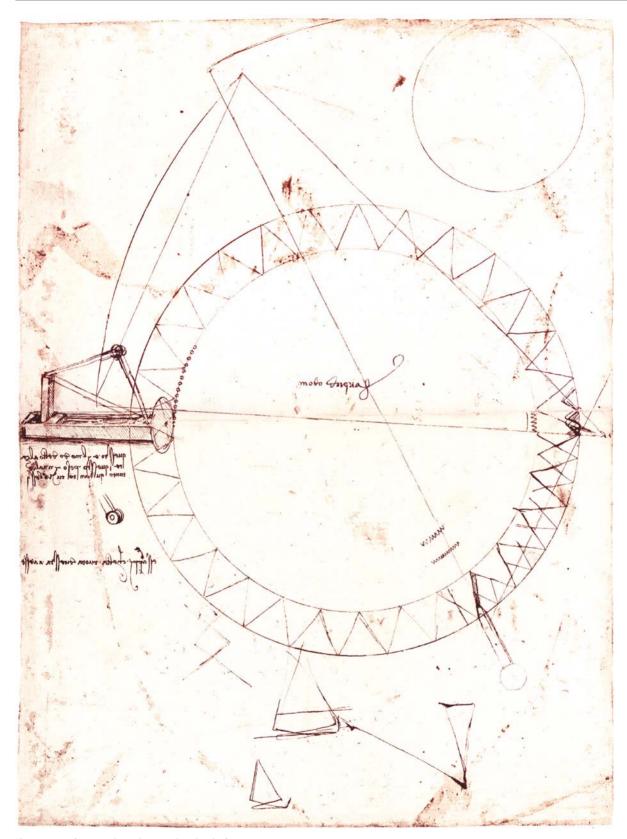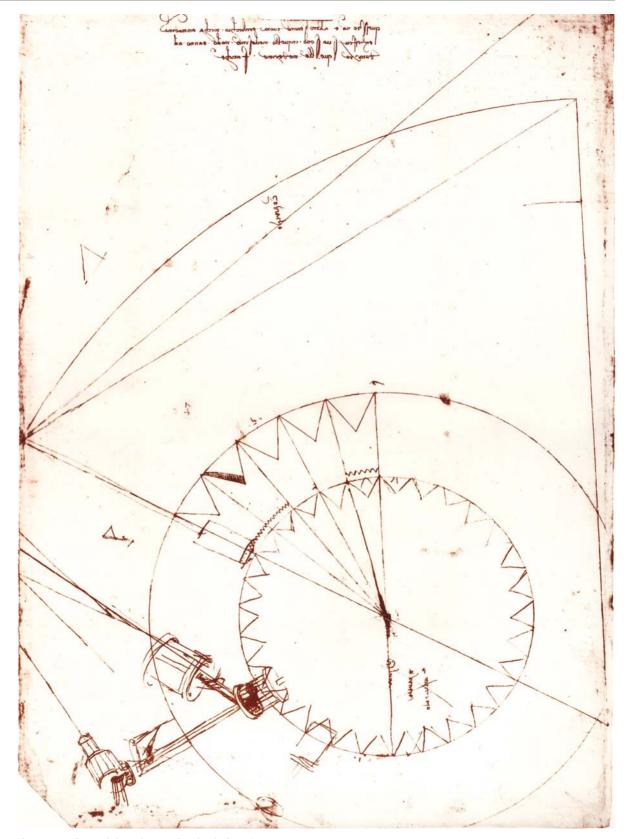
Fig. 2.27. CA, f. 339 r-a [926 r]. Secondary level of gearing

Fig. 2.28. CA, f. 347 r-b [956 r]. Secondary level of gearing
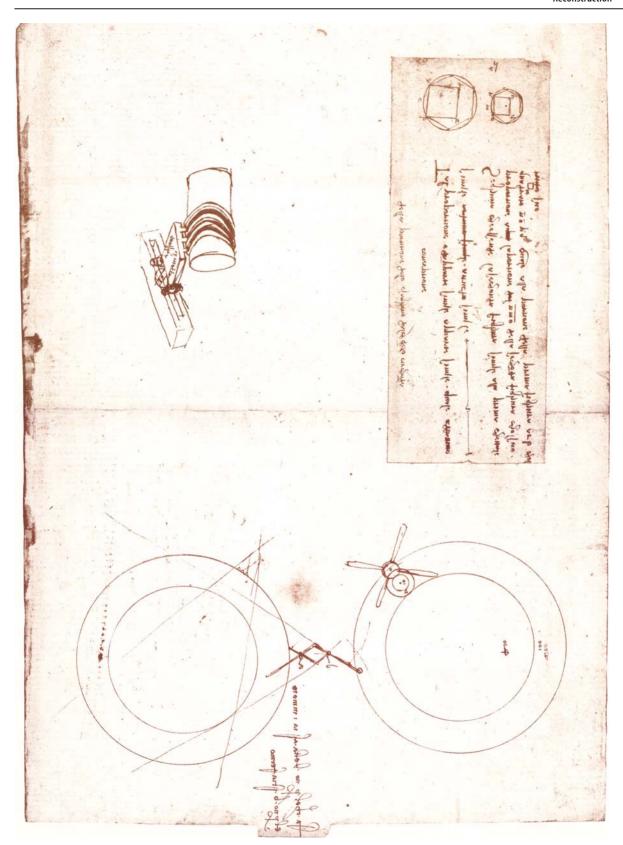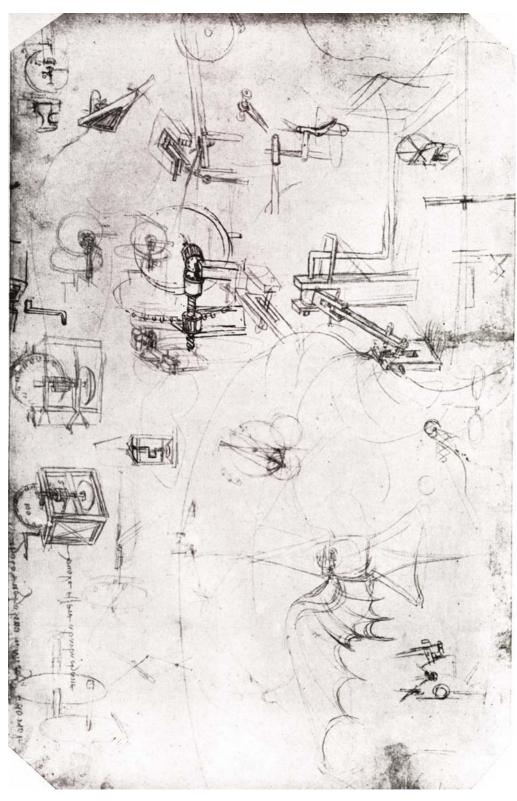
Fig. 2.29. CA, f. 347 r-b [956 r]. Multi-grooved sinusoidal cam

Codex Atlanticus f. 347 r-b [956 r] (Fig. 2.29) is interesting as it shows elements in other drawings such as the multi-grooved sinusoidal cam mechanism shown in "A Draped Figure and Studies of Machinery," 447 E Uffizi r (Fig. 2.30). There is also the

Fig. 2.30.
447 E Uffizi r. Draped figure and studies of machinery

Fig. 2.31.
447 E Uffizi v. Preliminary
studies for automaton

verso of the same Uffizi sheet (Fig. 2.31) for very early fragmentary studies of the automaton. In *Ashmolean Museum* P. 18 (VII), (Fig. 2.32) some of the small sketches may be predecessors of those shown at the bottom of CA, f. 296 v-a [812 r] (Fig. 2.20).
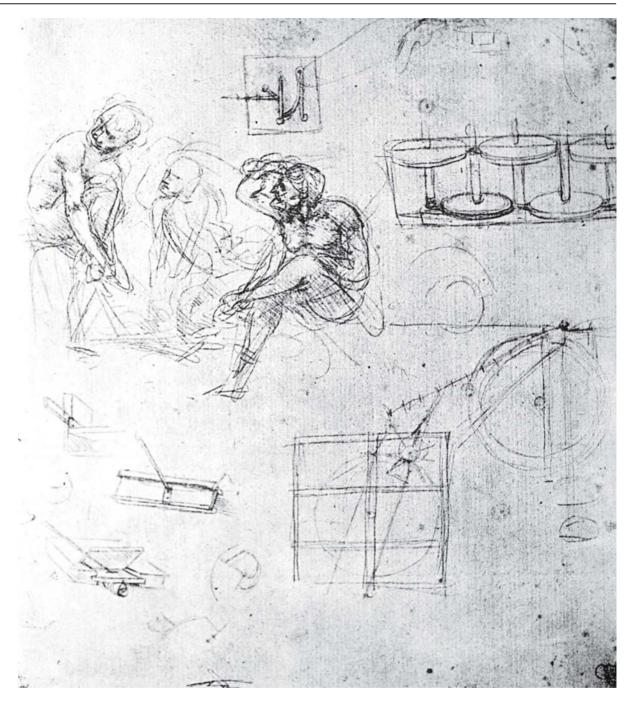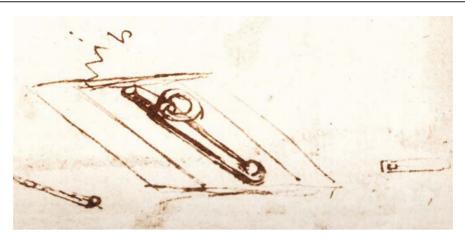
Fig. 2.32. Ashmolean Museum P. 18 (VII). Preliminary studies for automaton
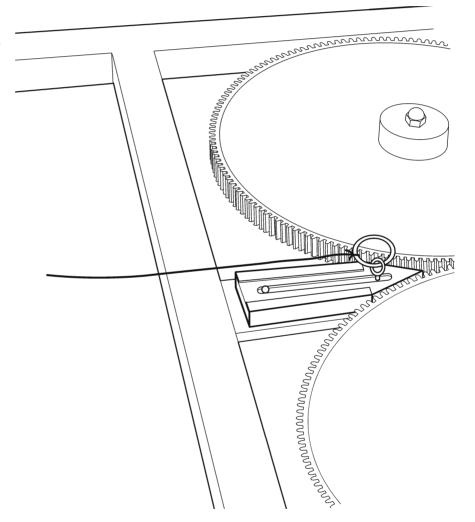
The triggering mechanism shown in CA, f. 296 v-a [812 r] (Fig. 2.33) is mounted underneath the center beam of the frame locking the two going barrel gears. A cord attached to the trigger plug when pulled, releases the gears and starts the machine (Fig. 2.34).

Although the above may simply represent early iterations, they may also represent additional or alternative drive trains. Perhaps rotating vertical shafts went up to power doors or other devices for various theatrical effects, such as rearing of the lion on its hindquarters and upon opening its breast, revealing its heart full of Florentine lilies.

Fig. 2.33.
Triggering mechanism
for automaton

Fig. 2.34.
Reconstruction of triggering
mechanism for automaton

Once I had put the pieces together, I needed to figure out if the automaton could indeed work. It's one thing to reconstruct how the automaton was made, but if I left it there I felt I would only have succeeded in putting together a mock-up of some elaborate bit of sculpture. I took some encouragement from Lomazzo, who wrote that Leonardo had found the way "to have lions move by the power of wheels" (*andar i'leoni per forza di ruote*). Surely, this meant the automaton had indeed worked as planned.

Operation

To understand how the mechanism worked, I began with Carlo's insight that the impetus for the system comes from the two springs below the large gears (Fig. 2.35). I reasoned the springs are directly connected to the large gears which drive the smaller pinion gears attached to the corner cog arbors. These same shafts drive the lantern gears and thus the mating spoked wheels for forward motion (Fig. 2.36).

Fig. 2.35.
Impetus for the system comes from the springs housed within their barrels

Fig. 2.36.
Front view of automaton

The coil springs mounted within the going barrels are regulated by a unique verge-and-crown wheel clocklike escapement mechanism based on the classic design (Fig. 2.37). Indeed, Leonardo would show a design using a verge and crown in CA, f. 314 r-b [863 r] (Fig. 2.38) which was reconstructed by Alberto Gorla (Fig. 2.39).
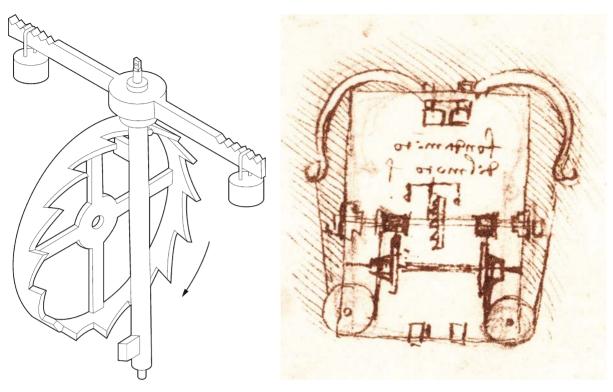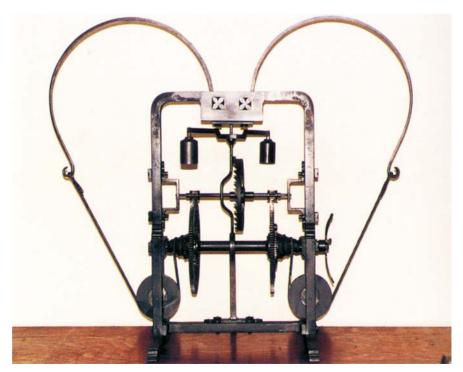
Fig. 2.37. Verge-and-crown escapement

Fig. 2.38. CA, f. 314 r-b [863 r]

Fig. 2.39. Reconstruction by Alberto Gorla

The crown, like its royal counterpart, is a ring of metal with teeth on the top edge. The verge is a bar of metal with paddles on both sides. Perpendicular to the verge is the foliot with adjustable hanging weights. Those paddles engage the crown teeth oscillating back and forth alternatively engaging and disengaging the crown teeth thereby regulating its rotation.

The crown (in this case a pair) forms the corner cogs and the verge is a toothlike oscillating member. Regulation is achieved through interaction of the corner cogs and escapement arbalests. The escapement arbalests correspond to and function in the role of the verge, albeit split, the pallets of the verge being the arbalest tips. The pair of corner cogs equate to the crown wheel, although this function is also split between the two. Drive wheels and their respective drive trains equate to the foliot or mass of the system. Dampening of the system is aided by the springiness of the escapement arbalests (Fig. 2.40).
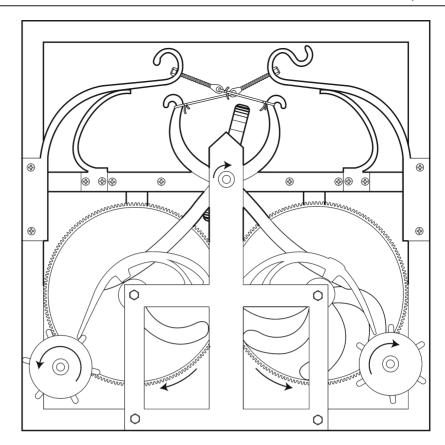
In operation, the corner cogs rotate toward their arbalest springs, which are phased one-half step apart from each other (Figs. 2.41, 2.42 and 2.43). As the system oscillates, one would hear a "click click click" as the corner cogs incrementally release the escapement arbalests. The automaton is wound by a corner cog in a clockwise motion, overcoming the greater resistance of the biased escapement arbalests. Perhaps it too generated a loud "clack clack clack" as it was wound up.

The array of cams attached to the top of the large barrel gears controls the direction and velocity of the automaton (Fig. 2.44). As the cams rotate together as a unit, they force the scissors-like cam followers to pivot. The cam followers are forced against the cams by the arbalest return springs via the criss-crossed cables. The steering cam follower connects the steering wheel thus turning it.
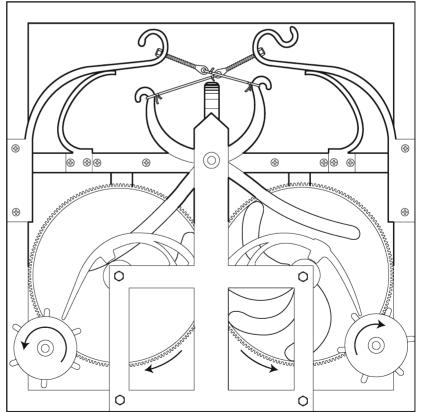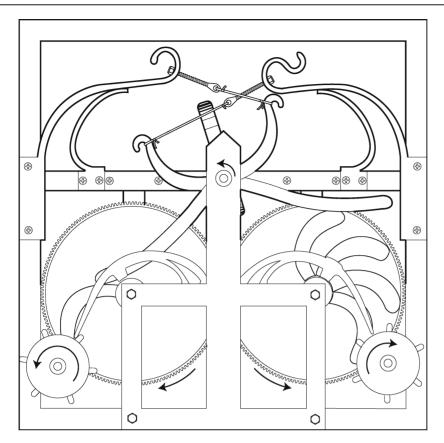
Fig. 2.40.
Dampening is aided by the springingness of the escapement arbalests

Fig. 2.41.
Corner cog/arbalest escapement

Fig. 2.42.
Corner cog/arbalest escapement

Fig. 2.43.
Corner cog/arbalest escapement

Fig. 2.44.
Array of cams attached to the top of the large barrel gears controls the direction and velocity of the automaton

Because Leonardo seems to indicate one "petal" or cam by the position of the cam follower, I reasoned that the propulsion cam onthe left-side large gear control speed rather than direction, perhaps even stopping the automaton briefly. The gear's basic operation is similar to the stackfreeds used to regulate the earliest spring clocks. In a stackfreed (Fig. 2.45), a cam attached to the top of the barrel has a spring-loaded arm pressing against it—the resistance matches the torque as the spring unwinds. Perhaps a few petal-shaped cams were used to slow or momentarily stop the automaton. The propulsion cam follower could also drive the rack-and-pinion subassembly. As the return spring pivots, the pinion moves up-and-down the rack, perhaps triggering a mechanism for ancillary devices such as a door (Fig. 2.46).

Fig. 2.45.
Stackfreed
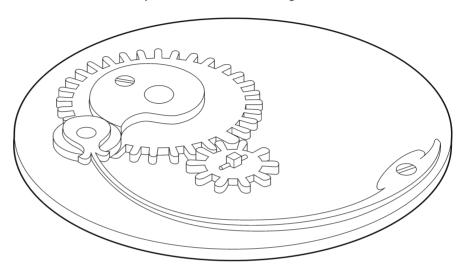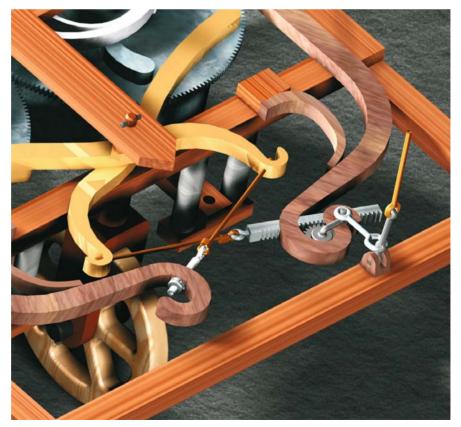
Fig. 2.46.
The pinion moves up-and-down the rack, perhaps triggering a mechanism for ancillary devices such as a door

Thus propelled, the automaton was capable of performing a variety of pre-determined movements that could be varied depending on the desired choreography and available space. Starting from a home position, the automaton begins to move forward and follows a preprogrammed course, stopping and starting, turning left and right. Special effects at any point could be introduced. The particular program is determined by the number, shape and location of cams on top of the two large cam gears. Each cam represents an individual instruction, or "line of code." The "program" is latent in these cams and is predetermined by the programmer, who might "debug" or modify his "program" with a file!

❖

I arrived at Rome's Fiumicino airport five days prior to the day of the lecture. Unlike previous trips to Italy, when I had spoken no Italian, I was now able to open my mouth and speak a few terrified words to my hosts. After riding the Metro from Fiumicio to the Stazione Centrale in downtown Rome, I was met by Rosie Fontanna, a free-lance publicist hired by the Biblioteca Leonardiana. Successful, self employed, and as it seemed with every Italian women I would meet on this journey, very beautiful, she was suffering from a cold in the April weather that was not much better than my native Minnesota. Pumping her inhaler while negotiating the mad traffic of Rome, Rosie drove me to my hotel. Thus began an almost Beatles-like odyssey of newspaper and magazine interviews. Prior to this little experience with fame, I had never understood why celebrities complained. Now I know: being "on" continuously, being shuttled from one interview to the next, just wears you out. And what I experienced must be the mild low-cal version. As the Beatles said regarding Beatlemania, "If it had continued we would have gone insane" now makes sense.

Thanks to *Cheap Sleeps in Italy*, I stayed at the charming little red tile roofed Hotel Coliseum, with its pieces of genuine Renaissance furniture and paternal concierges. After the long jet ride I took my ritual shower and quick lay-down on my little cot. But sleep was out of the question. I was in Rome! And I had to make the most of my one free day in the city that all roads lead to. Rallying, I asked the manager to get me a cab. A overweight, loud, dressed in American tourist shorts and tee shirts American family also asked for a cab. They attempted to steal mine when it came and the manager ran out and rescued me, from the American father, who was saying his tourist version of grazie, which came out as "grazy." My first stop was the Vatican Museum, which I had missed on my last stay. Fighting the jet lag that was making any horizontal surface attractive as an emergency bed, I entered into the world of ancient Rome and the Renaissance. Even though I had been in the National Museum in London, I was not prepared for the vast quantity of ancient statues with their sightless gaze and corridor upon corridor of marble. I found Leonardo's painting of St. Jerome tucked away in a small room and covered with a piece of Plexiglas that could have been purchased at the local hardware store. As I wound my way through the treasures, I stopped to photograph the *Laocoön* and to marvel at the titanic fragments of ancient statues, including a Roman head of Emperor Constantine the size of a VW Bug. Following the halls, corridors, and courtyards, I at last entered the Sistine Chapel, with its recently restored frescoes by Michelangelo. Like everyone except the babies in their recumbent strollers, I strained my neck to view one of the great wonders of the world. Every now and then the growing noise would be interrupted by a "shush" from the guards. After a long but blissful afternoon I called a cab, returned to my hotel and then headed out for dinner. Well fed by a waiter who only wanted to communicate to me in English, I returned at last to go to sleep, only to be awakened early by my alarm.

The publicist, who arrived downstairs late, complained about someone screaming in the night. We were chauffeured in a black Mercedes sedan to a studio in Rome, where I was scheduled to appear on the national Italian morning talk show for RAI 1,

"Uno Mattina." As is common in Rome, where armed guards stand outside of banks and high-security diplomatic convoys watched over by men in black sporting ear buds are a daily occurrence, there was a big security check at the studio's gatehouse. My passport was scanned, checked and entered into a database before I could enter. We were ushered into the complex, and I passed a heavyset, bearded gentleman who had just been interviewed. He could have been Pavarotti as far as I knew. Luca Giurato, the show host, is middle aged, tall, with salt and pepper hair and glasses. Very affable, he met me before we went on the air, and was kind enough to be impressed by my little Italian. In the dressing area, very young and pretty make-up girls sprawled in make-up chairs intended for arriving guests—no doubt done in from late night partying. The expensive art Deco set was very impressive with a large video monitor display playing my videos accompanied by music, and I couldn't help but feel intimidated by the big studio cameras. Luca helped me by telling me to look at him, not at the cameras.

Fortunately, I was given an earpiece and the translator who had lived in the Midwest simultaneously translated Italian into English for me and vice a versa for the broadcast. I expressed my gratitude at the honor of speaking at the birthday party of Italy's greatest artist and described my work, which was propped up on a stand. I had brought along my latest wrist design, the Omni-Wrist III, and demonstrated it for the television audience. Probably the scariest moment was when the host asked me to speak some Italian. I leaned forward and, squeezing my thumb and finger together tightly, replied, "il mio italiano è poco"—my Italian is little—a short phrase taught to me by Rossana Pedretti. This got a big response from our host, who said, "your Italian is perfect."

The morning went on with more interviews and then an appearance on a young people's television program, Tech 4 U. The show host, who started as a LA street performer, moved to Italy and parlayed his charm into his own television program. After the filming I was dead tired, but there was more to come. My next stop was Florence, so I boarded a train North to Vinci for a photo shoot with the famous paparazzo photographer Maximo. I was picked up by the wife of the Director and driven to Vinci by the Bibliteca chauffeur, but not before I hit one of my favorite rare book stores and purchased a rare first edition of Leonardo's Codex Trivulziano. Maximo was the last to photograph Princess Diana before she died. Though I had my doubts about my appearance by that time, my publicist said I "looked beautiful" and had the make-up adjusted for the shoot. I posed with various Leonardo models and when I finally got a Xerox of the article, I saw the hilarious results of my on-the-fly makeover: with my matted hair I looked like a freak. But I was beautiful—or so said my agent. The final event of the evening was a late night practice reading of my paper with the Biblioteca director's wife.

The day of the lecture I woke up early and took advantage of my limited free time to make a pilgrimage to Leonardo's birthplace. As I followed the winding medieval streets, I passed the church where Leonardo was baptized centuries before and felt a growing sense of wonder that I could be walking on cobblestones that held his footsteps from so long ago. Continuing on, I left town and started on a path to the birthplace, as signs of civilization started to fall behind me. Telephone poles and powerlines faded away, and older and older buildings came into view. When I arrived at his red tiled house, a two roomed, one story stone structure with a substantial stone outbuilding, I was immediately struck by the Vinci coat of arms: a lion wearing a knight's helmet—an heraldic representation of his name and a merger of his two robotic projects!

Reading this as a sign from God, I returned to Vinci with more than a little relief, and gave my lecture in English with simultaneous Italian translation. After the applause died down, I gave interviews to local newspapers with the usual questions about the evil potential of robots. Significantly, I was also asked by Monica Taddei

(Dr. Nanni's wife) if I would give Paolo Galluzzi an advance copy of my paper complete with illustrations. As I had worked with him in the past I granted that request. He now had all the technical information necessary to build a working model.[18]

The event was arranged almost like a pageant, thanks to the wonderful sense for drama and spectacle so close to the Italian heart. I was delighted to meet the beautiful blond haired, blue eyed and accomplished young Leonardo scholar, Simona Cremante, who accompanied me to several newspaper interview and photograph opportunity with the mayor of Vinci. We were then chauffeured in the Biblioteca's car to a villa in the wine country where the celebration was held. There I met up with my publicist and her assistant and posed for yet more photographs. Then two ranks of guests formed in front of the nineteenth-century villa entryway. They lined up behind me and, with Mayor Faenzi leading the procession, we walked inside, where we were first to partake of a beautiful buffet of Italian delicacies. Feeling quite at home, I loaded up my plate like it was Christmas at the folks'. But when I sat down I learned my mistake—everyone else had taken small portions of the first course only. Simona explained that you were supposed to go back for each successive course, so I unloaded food onto her plate and was amused to see her devour it all without my Yankee sense of shame. Then a very warm, huge Italian shook my hand, and although he couldn't express it in English, it was apparent he simply loved me for my work. Upon leaving, I also met the chef who was responsible for the feast and praised his effort, after which we went back to Leonardo's birthplace and wrote our names in the visitor's log book.

I went back to Firenze on the train with Simona, and we talked about Orson Welles' movies all the way. I then got a train to Rome, and by the time it arrived it was too late for me to catch the last train to the airport Holiday Inn. At the station I was met by a serious-looking, dark-haired heavyset man who, except for his clipboard, would have fit well in any of the Godfather films. He sent me on my way in an unmarked cab. Once inside, I began to wonder if I was being taken for a ride in a rogue taxi. After a long search in which the driver, in spite of stopping at restaurants for directions, couldn't find the hotel, we realized that the hotel was actually a few miles outside of the airport. But the driver had tried so hard I still tipped him. At last, in my American hotel, I could take a bath and shower and sleep on a bed with box springs!

Leonardo's programmable automaton is the first record of a programmable analog computer in the history of civilization. We see in it Leonardo's first design effort in planning automata culminating in his fabulous Robot Knight,[19] of about 1495, a practical entertainment piece based on his pioneering study of biomechanics.

Leonardo's sophisticated use of mechanisms at a very early age further highlights his talent in producing a design that simultaneously combines marvelous compact packaging, complex guidance and control.

Postscript: Building Leonardo's Programmable Automaton
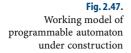
After several years of fruitless efforts to raise funds to build Leonardo's programmable automaton, including a near miss with Britain's ITN for a program on Leonardo,[20] I decided to build a prototype myself in August of 2004.

Utilizing the computer aided design (CAD) model shown above as blue prints, I headed to my shop. I followed the above design without any "updates." The most

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[18] Vanderbilt Tom, "The Real da Vinci Code," *Wired*, November 2004, pp. 210–229.

[19] The Uffizi and Oxford sheets contain studies for an *Adoration of the Shepherds* on which Leonardo was working in 1478, thus confirming the proposed date for the programmable automaton. Cf. A. E. Popham, *The Drawings of Leonardo da Vinci,* New York, Reynal & Hitchcock, 1945, plates 50 and 51.

[20] *Leonardo's Dream Machines*, Airdate: 25 Febraury 2003, ITN Factual, London, producer: Paul Sapin.
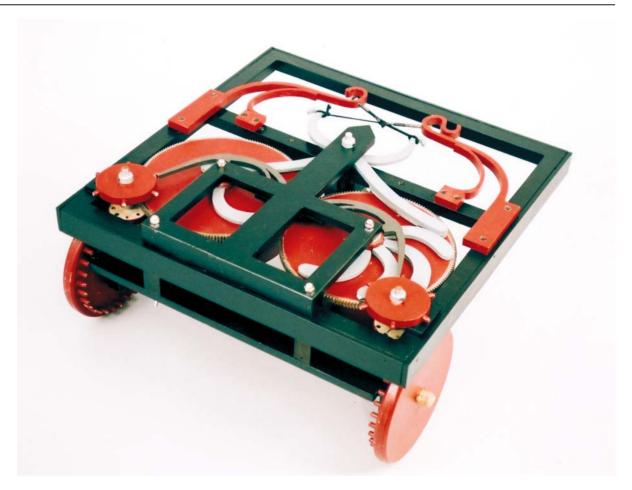
tedious task was the wooden cogs and lantern gears because they required a large number of accurately spaced holes for the pegs. Firing up my vintage WWII Sheldon lathe, I set up a miniature peg factory. I purchased stock steel gears (I was not going to subject myself to cutting my own gear teeth).

The question of whether Leonardo would have used wood or metal for these gears and their pinions is an interesting one. Considering how small the teeth are, as well as the torque and abuse the cart would have to endure, I would argue that metal (although not necessarily iron or steel) would be probable. Any clock maker of the time could have fabricated gears for him, but considering this early stage of his career and the lightness of his pocketbook, he may well have used punch and file himself. The stock metal gears that I bought were amazingly close in pitch, diameter and tooth profile to those of Leonardo (Fig. 2.47). I took this as a good sign.

Another challenge was the arbalest springs for the cam returns. Although Leonardo may have made these from bent wood, he also may have considered horn or even bone as contemporary plastic like materials. I was willing to settle for model airplane grade plywood so that I could easily cut the intricate curvilinear shapes with my saber saw. As Leonardo would have, I used bronze bushings with integral flanges for all the bearings, which I purchased at the local hardware store. Cost effective and elegantly simple, they reduced the cart's friction to a minimum.

Actually building made Leonardo's intentions even clearer (Figs. 2.48–2.50). We can see from the top perspective figure of CA, f. 296 v-a [812 r] (Fig. 2.15) that Leonardo is after compactness in overall height as well as in width and breadth. This he accomplished by locating (as is the case in almost all previous reconstructions) the pair of drive wheels as high as possible. Because the drive wheel pegs are near their outside diameter, the lantern gears are mounted near them to enable them to mesh successfully. Consequently, this relationship defines the framing system, with the lantern gear dividing the upper and lower frame. Because of the lantern gear and the wheel meshing it is not possible for the famous zigzag bracing to be located on the inside of the lantern gear where it would collide with the coil springs. Therefore it is more likely that it would hang from the upper frame and could extend all the way down and tie into the lower frame for maximum support partially covering the wheels. However, this is not what Leonardo shows in the upper figure of CA, f. 296 v-a [812 r]. Instead, he seems content to have the upper frame extend down a short distance,

terminating in a separate and distinct complementary lower frame. This is another reason that I have connected the steering wheel to the upper frame only. Also, building the model made it clear to me that the combination of the arrow-like top frame, in conjunction with the main frame below, is adequate for supporting the steering wheel shaft.

It should be also noted that the area where the framing, lantern gear and drive wheel mesh is one of the most critical and confusing portions of the upper drawing of CA, f. 296 v-a [812 r]. (This also occurs again in the Chapter IV the Bell Ringer with CA, f. 5 r-b [20 r] in the helix area of the "Bottini.") Leonardo tends to keep overlaying critical elements in the area that interests him until their relationship to one another becomes almost indecipherable.

The switch to start the cart identified above was most likely a plug wedged between the two large gears and pulled out by a cord. It would be ridiculous to assume that the cart would travel with the cord trailing behind it. Pulling the plug, literally, would do the opposite of stopping the cart and would actually start it moving. The remote control feature would facilitate the illusion of autonomous action—leaving the cart free to go on its mission.

The escapement mechanism is perhaps the most critical and difficult to adjust. Unlike the verge and crown, the arbalest springs have no swinging mass connected to them. In an actual verge and crown, the acceleration and deceleration of the swinging mass dampens the engagement of the verge teeth with the crown. Although there is the mass of the cart's drive train, it is critical that it be tuned to the tension of the arbalest springs to slow the escapement corner cogs. The above comments about materials for the cam return springs also apply here. Leonardo may have resorted to

Fig. 2.48a. Working model of programmable automaton
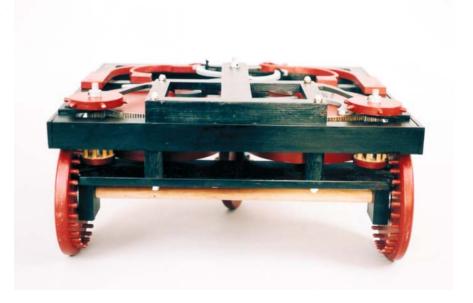
Fig. 2.48b. Corner cog/latern gear/pinion assembly

exotic material for the arbalest springs, perhaps using horn or bone, using their capacity for fine detail to make minute adjustments to their engagement with the escapement corner cogs. Too much stiffness and the escapement mechanism is locked and the cart is static; too little and the escapement runs wild, propelling the cart out of control. A balance must be struck between friction and pressure on the upper corner cogs to simulate the inertial effects of the verge and foliate. Spring torque, friction and compliance of the springs all must be balanced.

Perhaps the most important validation that this model provides is the proof that the cam "program" makes the cart capable of turning left, right, or running straight. Indeed, what Leonardo shows in the center top view of CA, f. 296 v-a [812 r] is half a dozen cams on the right side of the right large gear. On the opposite side of the same gear there are none. This produces a left/right turning of the steering wheel—the two extremes (Figs. 2.51 and 2.52). This is assuming that Leonardo intended full-length cams. A medium-length cam would result in the cart's going in a straight line (Fig. 2.53) or, in other words, no rotation of the steering wheel from centerline. The

Fig. 2.53.
Straight line motion produced by medium length cam
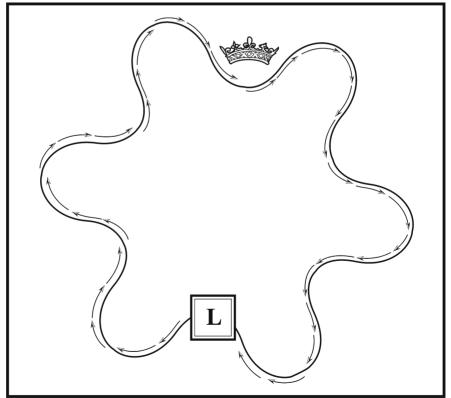
Fig. 2.54.
Pattern of the circle may be altered by mixing in odd size cams creating a wavy circle

turning radius is large as the steering wheel can only turn plus or minus approximately 20 degrees. The cart completes its program in approximately four and half feet of travel. This would seem to have little practical use however the cams may be used to create large circular patterns by providing a constant bias to the steering wheel. All long cams or all no cams would drive the cart in a large circle, with the direction (clockwise or counterclockwise) depending on the placement of the long cams. The pattern of the circle may be altered by mixing in odd size cams creating a wavy circle for example (Fig. 2.54). One can imagine Leonardo, the first "programmer" staging an event the fifteenth century. In addition to his file he would simply keep a pocket full of various length cams (Fig. 2.55)—plugging them into their respective sockets for various "programmed" movements!

The supreme thrill came when I had finished drilling evenly spaced holes in the large gears to secure the cams, which have a mating pair of pins sticking out from their bases. I then manually rotated the large gears via the drive wheels and stepped back to watch the cart's cam wheels rotate and turn the steering wheel from right to left. Leonardo's cart was executing its program for the first time in over 500 years.

Fig. 2.55.
Variety of cams

Leonardo's Knight

Tell me if ever, tell me if ever anything was built in Rome …

Leonardo da Vinci, CA, f. 216 v-b [579 r] c. 1495

Carlo Pedretti was the first to discover the tell-tale fragments of Leonardo's Robot Knight in the Codex Atlanticus.[1] My effort to interpret and reconstruct Leonardo's Knight began with my book *Robot Evolution* and would lead me on an odyssey around the world. It would take me three generations to get it right, finally coming to me in, of all places, my local gym. The armored Robot Knight sat up; opened its arms and closed them, perhaps in a grabbing motion; moved its head via a flexible neck; and opened its visor, perhaps to reveal a frightening physiognomy. Fabricated of wood, brass or bronze and leather, it was cable operated and may have been built for a grotto similar to those built by Salomon de Caus (1576–1626)[2] perhaps with the accompaniment of automated musical instruments.[3]

What was the occasion for Leonardo's original Robot Knight? What patron required such a splendid demonstration of his wealth and power? Leonardo's project for the Robot Knight may have dated to the time of his work on the Last Supper and the decoration of the Sala delle Asse at the Sforza Castle, a period of some five years (1494 to 1498).

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[1] Leonardo da Vinci, *Fragments at Windsor Castle from the Codex Atlanticus,* Carlo Pedretti (ed.), London, Phaidon, 1957, pp. 39–40, no. 12705. See also his later *Leonardo Architetto*, Milan, 1978 (English edition, London, 1986, and New York, 1991), pp. 319–323. In his edition of the Madrid manuscripts (New York, 1974), vol. III, Commentary, p. 76 note 13, Ladislao Reti mentions the robot sheets in the Codex Atlanticus as follows: "On fols. 366 r-b [1021 r] and 216 v-b [579 r] of the Codex Atlanticus, different armor parts are sketched. They do not belong to an actual suit of armor. The articulations are clearly shown, indicating that the project was for an automaton in the form of an armored warrior. Perhaps the armor parts shown belong to the same project." A reproduction of the central part of f. 366 (recto and verso) with the Windsor fragment RL 12705 in place, is given in the exhibition catalogue *Leonardo da Vinci, Studies for a Nativity* and the "Mona Lisa Cartoon," edited by Carlo Pedretti, Los Angeles, University of California, 1973, pp. 27–28, figs. 5 and 6. See also Pedretti's chapter on 'Anathomia Artificialsis' cit. in Chapter I, note 25 above, vol. II, pp. 868–871. I do not know of any other reference to Leonardo's robot studies. See, however, my own *Robot Evolution: The Developent of Anthrobotics*, New York, Wiley, 1994, pp. 12–20.

[2] Salomon de Caus, *Les raisons des forces mouvantes avec diverses machines tant gue plaisantes*, Frankfurt a. M., 1615. Cf. Bertand Gille, *Engineers of the Renaissance*, Cambridge, Massachusetts, MIT Press, 1964 (original edition in French, Paris, 1966), p. 236. See also the paper by Luigi Zangheri cited in note 17 below. Concordance as given by Ladislao Reti in his edition of the manuscript (as in note 1 above), p. 76 (CA, f. 36 r-a, b [100 r, 101 r] and v-a, b [102 r, 103i r]).

[3] See Leonardo's description of the garden planned for the suburban villa of Charles d'Amboise in Milan, CA, f. 271 v-a [732iii v], c. 1508: "With the help of the mill I will make unending sounds from all sort of instruments, which will sound for so long as the mill shall continue to move." Cf. Carlo Pedretti, *A Chronology of Leonardo da Vinci's Architectural Studies after 1500,* Geneva, Droz, 1962, p. 38. See also, by the same author, *Leonardo da Vinci. The Royal Palace of Romarantin,* Cambridge, Massachusetts, Harvard University Press, 1972, pp. 52 and 98, as well as the Richter *Commentary*, vol. II, pp. 29–31. Leonardo was certainly acquainted with late fifteenth-century examples of garden design, including those of Poggio Reale at Naples and the Rucellai at Quaracchi near Florence. It was for Bernardo Rucellai that he planned an ingenious water-meter for irrigation, as shown by a document that Pedretti discovered in Venice in 1951, namely the Golpaja Codex, that mentions a robot (a wooden man).
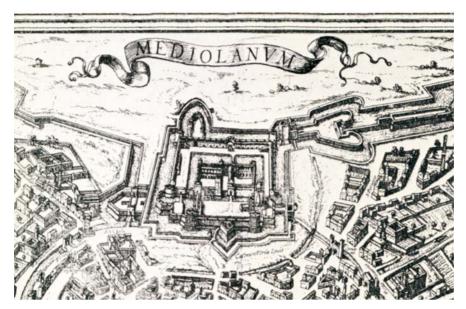
In Leonardo's time, important political events called for impressive displays of pageantry. The years 1493 and 1494 were of special significance to the shrewd politics of Ludovico Sforza. The wedding of his niece, Bianca Maria, to Emperor Maximillian I forged closer ties between Sforza and the emperor, thereby ensuring a speedy recognition of Ludovico's title as Duke of Milan following the death of the young duke Galeazzo Maria Sforza at Pavia in 1494. In the same year, Ludovico instigated the French king, Charles VIII, to move down to Italy against the king of Naples. Any of these events and their associated celebrations could have provided an occasion for the appearance of Leonardo's technological wonder. As Carlo Pedretti has suggested to me, a suitable setting for the robot's first appearance could have been the park of the Sforza Castle. Embellished by Galeazzo Sforza, it was later abandoned and almost torn down before being restored by Luca Beltrami at the turn of the last century. The castle was constructed by Francesco Sforza as his residence and fortress, complete with moat, in 1450 (Fig. 3.1).

Access to the park from the ducal apartments was through Bramante's bridge, the ponticella, over the moat by the northeast tower of the Castle, where the Sala delle Asse is located. The park is best known for an elaborate pavilion at the center of a living labyrinth—a setting recorded by Leonardo himself, and was a place selected by him as a sort of testing ground for his inventions and experiments.[4]

The Sala delle Asse, a variation on the theme of the Renaissance grotto, is composed of a painted forest canopy on the ceiling and images of tree trunks lining the walls. The purpose of the room other than as an extension of the park, perhaps as a renaissance Tower of the Winds (see "Bell Ringer", below) providing both education and entertainment,[5] is long lost. It may have been intended as a man-made microcosm in which to display automata such as the Knight.

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[4] It would be enough to mention the closing paragraph in the famous letter of Ludovico Sforza (CA, f. 391 r-a [1082r], c. 1482, Richter, §1340): "And if any of the above-named things seem to any one to be impossible or not feasible, I am most ready to make the experiment in your park …". See, however, for other pertinent reference to the park of the Sforza Castle, Richter *Commentary*, vol. II, pp. 31–32 and 186.

[5] Volker Hoffmann, "Leonardos Ausmalung der Sala delle Asse im Castello Sforzesco", in *Mitteilungen des Kunsthistorischen Institutes in Florenz, XVI,* 1972, pp. 51–62, for recent interpretations of the symbolism of the Sala delle Asse; John F. Moffitt, Leonardo's «Sala delle Asse» and the Primordial Origin of Architecture", in *Arte Lombarda*, N.S., nos. 92–93, 1990, 1–2, pp. 76–90; Dawson Kiang, "Gasparo Visconti's Pasitea and the Sala delle Asse", *ALV Journal, II,* 1989, pp. 101–109. See also Carlo Pedretti, *Leonardo. A Study in Chronology and Style.* Berkeley and Los Angeles, University of California Press, 1973 (2nd Ed., New York, Johnson Reprint Corporation. Harcourt Brace Jovanovich Publishers, 1982), pp. 76–77.

Fig. 3.2. Dungeon under the Sala della Asse

Leonardo's whole project inevitably included, perhaps even culminated, in the fashioning of a robot man. In his humanistic philosophy, man was the microcosm: the universe writ small. Leonardo's Knight, when viewed in a man-made microcosm such as the Sala delle Asse, would have embodied the Renaissance ideal of "man as the measure," the standard for which the world was designed. As an official reception space, the room might have been a *Wunderkammer*, or chamber of wonders, with the Robot Knight perhaps popping out of a rocky wall.

There it would have been one of the wonders that Ludovico could have displayed to impress important visitors like Charles VIII of France. According to French historian Albert Mousset, a "fully armed" warrior appeared at the Grotto of Perseus at St. Germainen-laye, 20 kilometers from Paris, on the occasion of the Dauphin's visit during its construction on September 1, 1608.[6] The builder, one Francini, later known as Thomas de Francine, was a native of Florence. He left drawings of other grottoes of the complex, which date about 1600 and were also engraved. They betray knowledge of the Pratolino Grottoes. It is interesting that both grottoes and automata become more common in Europe at the approximate time that the Madrid manuscripts were transferred by Pompeo Leoni from Milan to Spain. Furthermore, the role of Juanelo Turriano in disseminating Leonardo's technological ideas in Spain is still to be fully explained. A native of Cremona, Italy, he was in the services of Charles V when, in 1533, he made a number of automata for his patron, though is best known for his grandiose hydraulic device for Toledo.[7]

A mechanical knight, one of a pair of jousters, was built in Germany in 1520 and is now housed in the Bavarian National Museum in Munich.[8] Could this have been inspired by Leonardo work? By the end of the sixteenth century, Leonardo's robotic ideas had come to full fruition. Thus in 1590 Lomazzo could record Leonardo's inventions, including the robot, stating that "all Europe is full of them."[9]
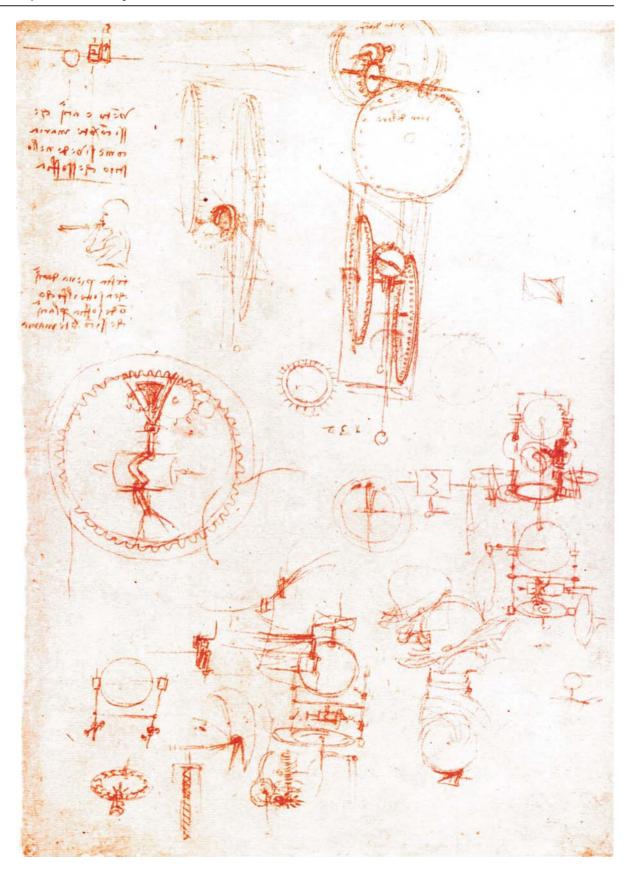
In 1997, bearing a letter of introduction from the Florence Science Museum, I made a field trip to the Sala delle Asse. Armed with facsimiles of Leonardo's notebooks from the period, I went to see if I could discover anything that might be useful for understanding his Robot Knight. I arrived at Milan's imposing fascist train station in a pouring rain that flowed out in torrents from the station's gargoyle downspouts. Making my way to the Sforza Castle, I made my introductions and was led off the beaten path to where no tourist was allowed to go—the dungeon. Now used as the museum's storage facility, it lies directly beneath the Sala della Asse (Fig. 3.2).

[6] Albert Mousset, *Les Francine. Crèatures des eaux de Versailles, intendants dex eaux et fountains de France de 1632 à 1784*, Paris, P. A. Piccard, 1930, as cited by E. Droz and A. Chapuis, Automata: A Historical and Technological Study, London, B. T. Batsford Ltd., 1958, p. 43.

[7] On Juanelo Turriano, his possible connection with Leonardo, and his work at Toledo, see Ladislao Reti, "A postscript to the Filarete discussion: on horizontal waterwheels and smelter blowers in the writing of Leonardo da Vinci and Juanelo Turriano (ca. 1565): a prelude to Besacle", in *Atti del XIII Convegno internazionale di Storia della Scienza*, Paris, 1971, pp. 79–82.

[8] Cf. Mary Hillier, *Automata and Mechanical Toys*, London, Bloomsbury Books, 1988, p. 25.

[9] Giovan Paolo Lomazzo, *Idea del Tempio della Pittura*, Milan, P. Gottardo Pontio, 1590, pp. 17–18. Cf. Beltrami, *Documenti*, p. 206.
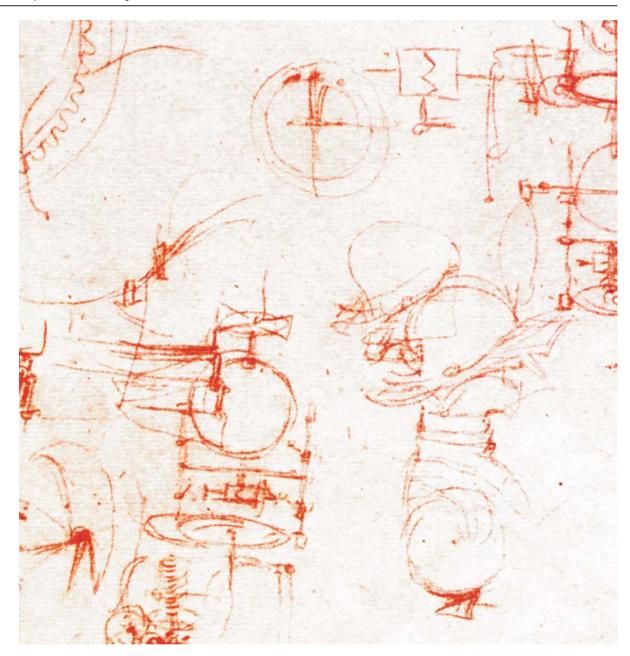
Ancient Roman tombstones were arranged in neat stacks on custom-constructed steel tables covered with plastic tarps. The cavernous room, with its large, Roman brick arches, seemed denuded of anything from Leonardo's time frame, with the exception of small stands built into the corners. In Leonardo's day these must have held torches. The moat had long ago been drained and is now a grassy ravine. At some point, perhaps centuries ago, windows had been cut into several of the meter-thick walls. However, my curiosity led me to the now-shuttered windows opening onto the long-gone moat. The first shutter I opened revealed—to my surprise—a giant snail, complete with probing eye stalks, slowly gliding across the window sill. Unable to stop myself, I opened another shutter and was startled almost to the point of falling backwards by a screeching cat, who arched her back in defense of her kittens. I would often think of these images as signs of things to come as I continued on my adventure into the world of Leonardo. The snail I would come to see as representing Carlo, his eyes wide open searching and probing for the truth, his gentle gliding along, so as not to disturb anyone, being well in keeping with the Renaissance motto *Festina lente* (hurry up slowly) that characterizes his approach to the study of Leonardo. And the cat guarding its kittens? The cat would be me struggling to protect my discoveries!

Pieces of the Puzzle

Four sheets of the Codex Atlanticus illustrate most of the elements of Leonardo's robot. Because a detail on one sheet might be explained or clarified by details on others, they must be considered as a group, not individually. I believe that these sheets must date from the same time, possibly closer to 1495 than to 1497, because of hints at their contents which are found in notebooks regarding the earlier date.[10] As a rule, I found that the more finished the sketch, the closer Leonardo is to finishing his thought. Leonardo in this time period draws in red chalk and then reinforces it in black ink. Finally, Leonardo's famous background slanting lines are added to put the figure in relief.

The left section folio CA, f. 388 v-a [1077 r] (Figs. 3.3 and 3.4) shows two small overlapping heads and one large head detailing the gorget (neck mechanism). The gorget's function is to protect the neck, provide secure attachment of the helmet, and still allow for flexibility. As applied to the robot, it conceals the mechanisms and protects the device from corrosion, which would have been an ever-present threat in a grotto. The gorget consists of three nested rings, or "lames," that create a flexible joint. This is detailed directly below the large head. In an actual gorget, multiple leather straps are riveted to the inside of the lames, holding the segments together while still permitting a degree of flexibility. In the large drawings of the head, the neck segments are inverted on the right. Some type of flexible central support is needed to prevent the rings from collapsing. The small tilted heads sketched in the center of CA, f. 366 v-b [1021 v] implies this (Figs. 3.5 and 3.6). Years later I would discover further neck/helmut drawings and perhaps even the face of the robot in Codex Forster

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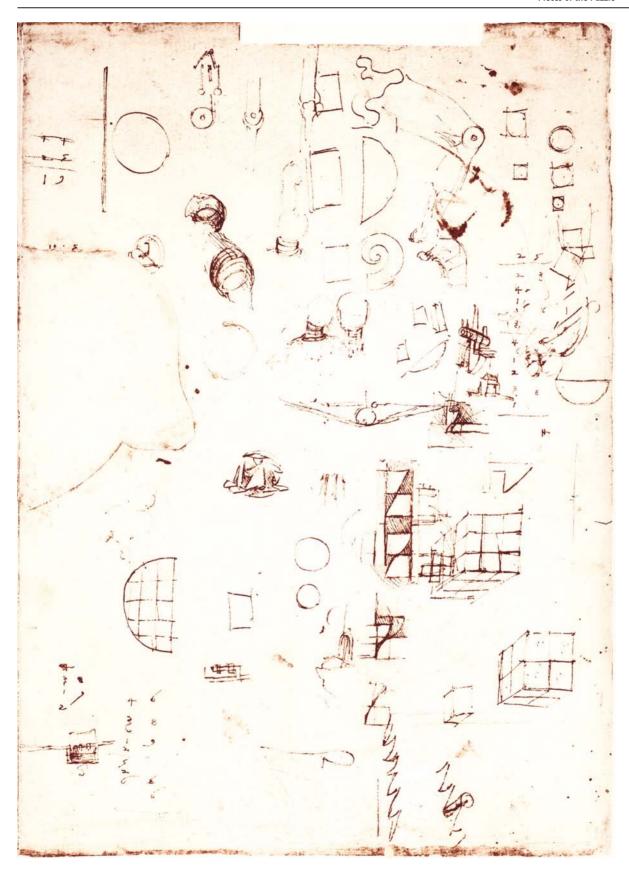
[10] A full discussion of the chronology of the three sheets in the pertinent entries of Pedretti's *Codex Atlanticus Catalogue* (as in note 22). The connection with two pages in Paris MS H, as discussed in the text above, may be taken to suggest an earlier date for the inception of Leonardo's studies for the robot mechanism. Carlo Pedretti agrees (oral communication) that Leonardo's first studies for the robot may date from c. 1494 at the time of a series of studies for musical instruments, mostly mechanical drums of a kind suitable for marching troops or individual soldiers, showing innovative ideas perhaps triggered by the French Army in transit through Lombardy in that year. This is the case with drawings of carriages and weapons in the same notebook as pointed out by Pedretti in his "The Sforza Horse in Context", keynote address at the symposium *Leonardo da Vinci's Sforza Horse. The Art and Engineering*, held at Lafayette College, Lehigh University in 1991, Bethlehem, Pennsylvania, Associated University Presses, 1995, pp. 27–39.
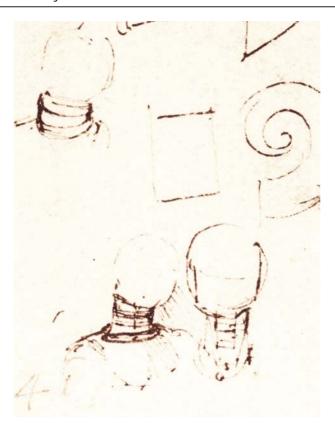
MS II,2, f. 65 r-v (Fig. 3.7). As Carlo described the striking similarity to the Codex Atlanticus drawings "they look like they were cut out of it." A drive train is also suggested by the cord diagram for the human neck on the *Windsor* anatomical sheet RL 19075 v (K/P 179 v) (Fig. 3.8) many years later.[11] Such cord diagrams, which duplicate every part of the human body, may have originated from Leonardo's robot studies, thus suggesting a new point of origin and practical application for his anatomical studies.

Fig. 3.4. CA, f. 388 v-a [1077 r] (left section). Helmut details

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[11] For a date possibly as late as the French period, c. 1517–1518, see Pedretti's catalogue entry in the corpus of the *Anatomical Studies*, cit. (as in note 1 above), vol. II, p. 882. It was about 1508 that Leonardo introduced cord diagrams in his anatomical illustrations to explain the mechanics of the human body, apparently in view of constructing and anatomical model. Cf. Pedretti's chapter 'Anathomia Artificialis,' (as in note 1 above).

Fig. 3.5. ▶
CA, f. 366 v-b [1021 v]
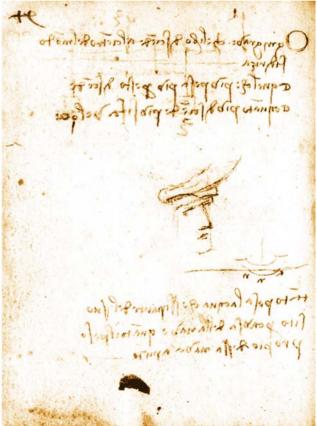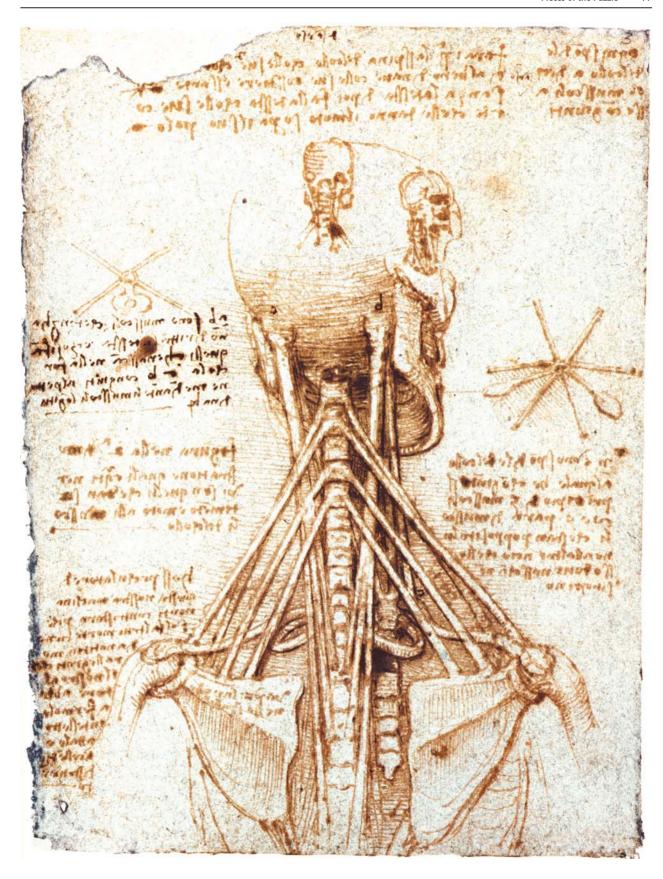
Fig. 3.6.
CA, f. 366 v-b [1021 v].
Head details
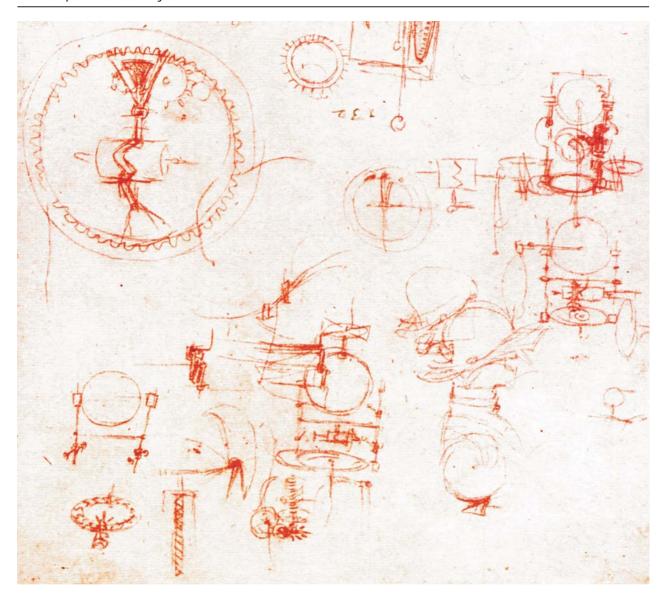
Fig. 3.8. ▶
Windsor anatomical sheet
RL 19075 v K/P 179 v

Fig. 3.7.
Codex Forster II,2, f. 65 r-v
▼
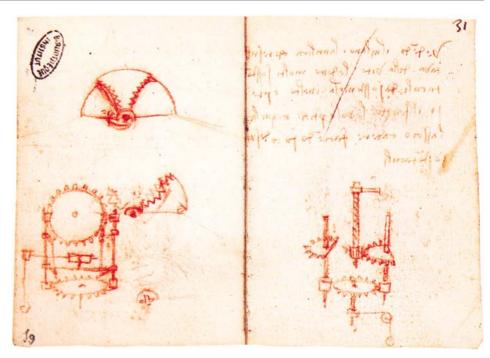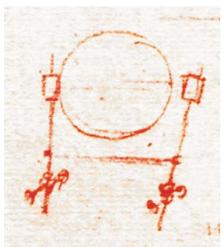
The three mechanisms drawn on the left section of CA, f. 388 v-a [1077 r] (Fig. 3.9) translate constant velocity (vertically-oriented rotary input) into a reciprocating rotary output at right angles. This could be interpreted as an escapement mechanism for a clock. Preliminary studies of this mechanism are in a notebook of c. 1494, Paris MS H, f. 113 [30 v] r – 112 [31 r] v, (Fig. 3.10) thus suggesting a date for this group of sheets.[12] The basic function of the machine is depicted schematically (Fig. 3.11): Two worms alter-

Fig. 3.9. CA, f. 388 v-a [1077 r] (left section)

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[12] See note 10 above. Of particular interest and beauty are the red-chalk sketches on ff. 43 v and 44 r, showing the estimation of human muscular effort with the help of a dynamometer. As explained by Ladislao Reti, "Leonardo da Vinci the Technologist: The Problem of Prime Movers", in *Leonardo's Legacy*, edited by C. D. O'Malley, Berkeley and Los Angeles, University of California Press, 1969, pp. 72–73 and figs. 1 and 2, in the figure on f. 43 v, no less than six different cases covering the whole body are examined, while in the figure on the facing page Leonardo tries to compare the force of the arm in different positions and points of attachment. Between the last two drawings a diagram (not reproduced by Reti) shows the arm as a compound lever. As such, it shows how kinesiology was indeed for Leonardo the foundation to his experiments in robotics. Compare also Paris MS L, f. 28 r, c. 1498, as given in the Richter *Commentary*, note to §378.

Fig. 3.11. CA, f. 388 v-a [1077 r]
(left section). Basic function of
machine
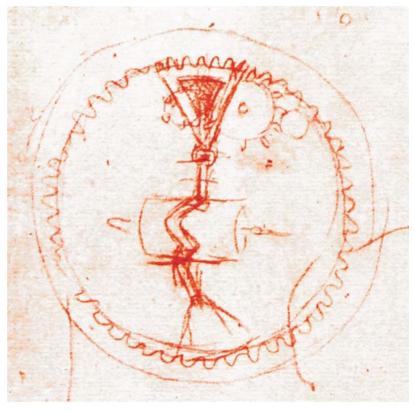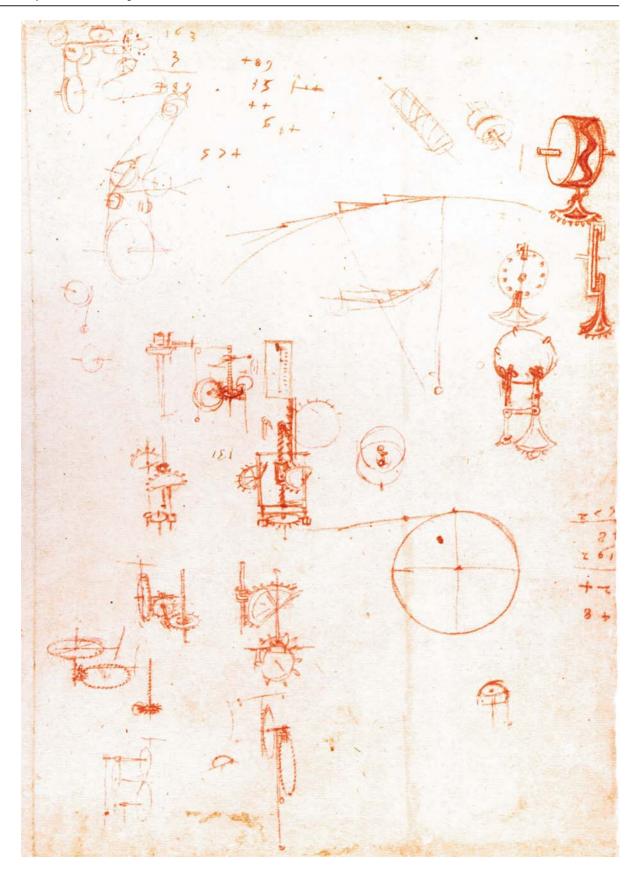
Fig. 3.12. ▶
CA, f. 388 v-a [1077 r] (left
section). Compacted version
of machine

nately engage a large worm gear providing high torque, their motion controlled by
the rotating drum cam. As far as I know this is the first time this mechanism has been
studied. Another version of the clocklike device, which may be an attempt at a more
compact design, is shown in the left section of CA, f. 388 v-a [1077 r] (Fig. 3.12).
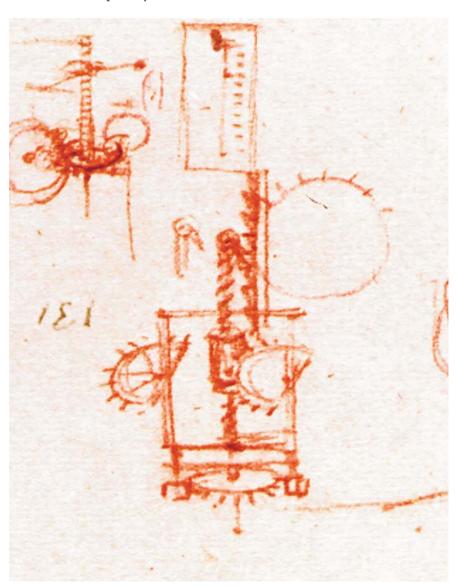
My first impression was that the above was a rudimentary programmable controller for the robot. In that case, it could drive the arm's pulley and cable system. Making the robot arms move up and down according to the "program."
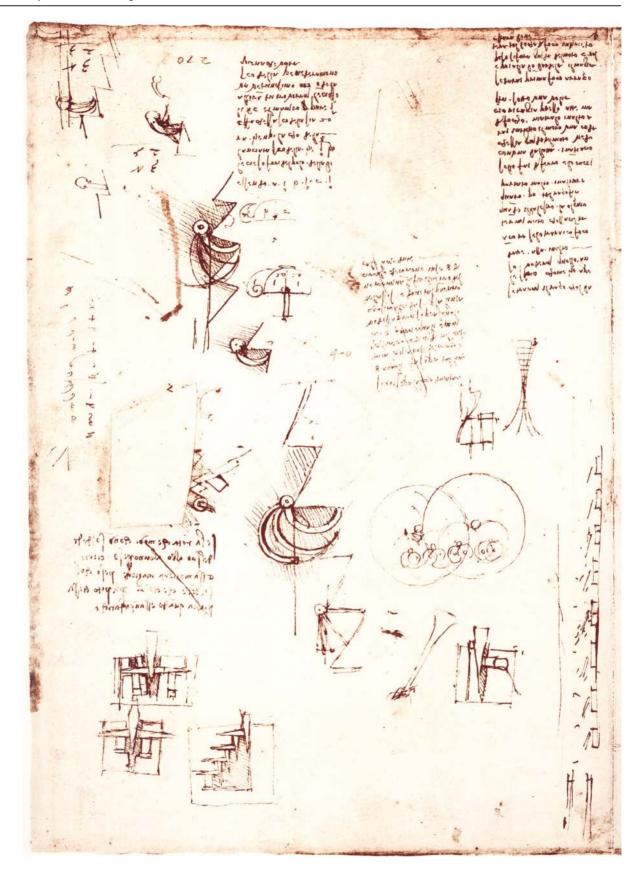
The right section of CA, f. 388 v-a [1077 r] (Figs. 3.13 and 3.14) shows a ratchet mechanism for producing vertical up-and-down motion by driving a paw that engages a toothed ratchet. The ratchet is detailed on CA, f. 366 v-a [1021 v] (Fig. 3.15). Perhaps this was for raising or lowering the Knight, assuming that a cable design was not used for the legs. A jack-like device hidden by the legs and connected to the torso could lift the Knight from behind. This would assume that the Knight was intended to be viewed only from the front, as would be the case if it were in a niche.

A wheel sketched, on the top left section of CA, 388 v-a [1077 r] (Fig. 3.16), is inscribed "rota dell' ore" (wheel of the hours), and another wheel is designated "rota del tempo" (wheel of the escapement),[13] thus showing that Leonardo is thinking of a clock mechanism, possibly in connection with the robot.

Fig. 3.14.
CA, f. 388 v-a [1077 r].
Detail of ratchet mechanism

[13] Carlo Pedretti, "Il Tempo delli orilogi," *Studi Vinciani,* Chapter III, Geneve, Droz, 1957, pp. 99–108.
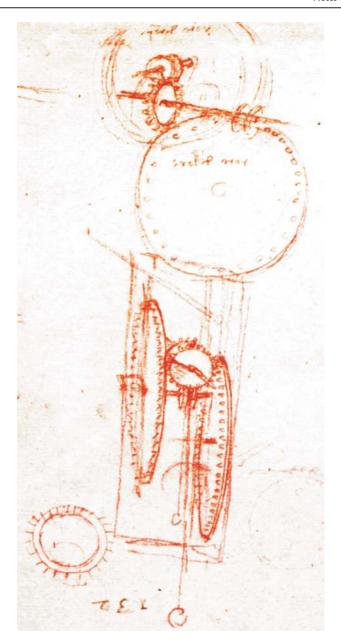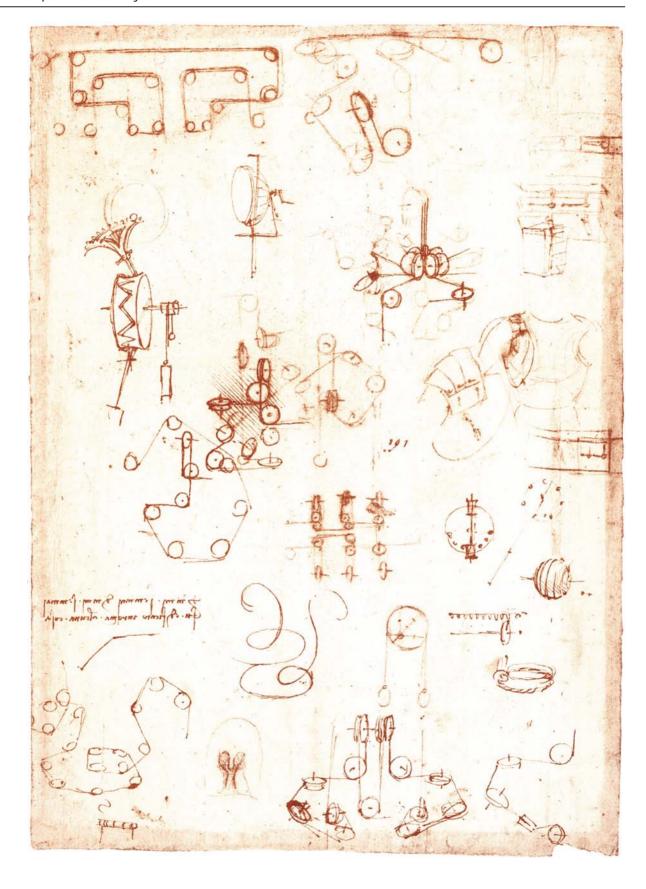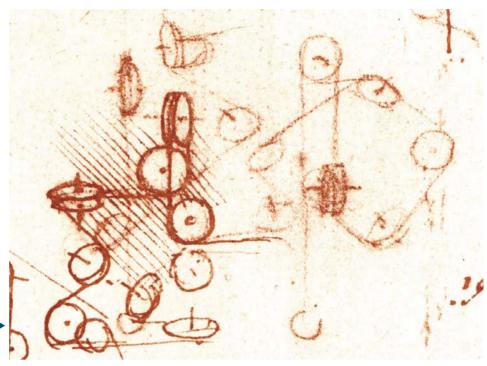
This same detail shows a pulley system, this time driven by a counterweight. This is of particular interest in a context that includes clock mechanisms because of Leonardo's well-known tribute to the inventions of Nature as being superior to any human invention: "she does not involve counterweights when she makes organs suitable for animals."[14] Counterweights are also shown in the related mechanisms sketched in Paris MS H, f. 113 [30 v] r–112 [31 r] v (Fig. 3.10). The center group of drawings of CA, f. 216 v-b [579 r] (Figs. 3.17 and 3.18) (in red chalk partially gone over with pen and ink), show counterweights.

In the small helmet shown on the left section of CA, f. 388 v-a [1077 r] (Fig. 3.4), the visor appears both raised and lowered. The jaw must have been articulated, but is shown removed from the head. The nose and outline of the head can be clearly seen

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[14] Windsor, RL 19115 r (C.IV.10 r), c. 1508–1510, given in the *corpus* of Leonardo's *Anatomical Studies* as 114 V, on p. 370. See also Richter, §837.

Fig. 3.18. ▶
CA, f. 216 v-b [579 r].
Counter weights
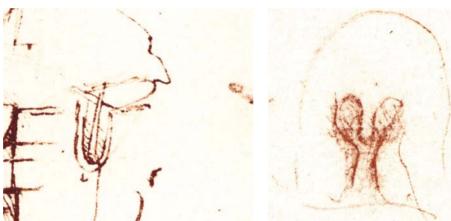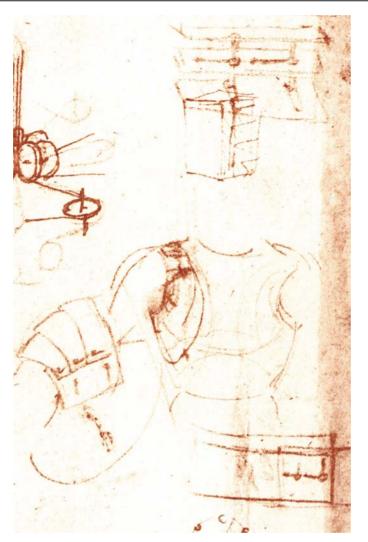
Fig. 3.19. CA, f. 366 v-b [1021 v]. Nose and outline of head
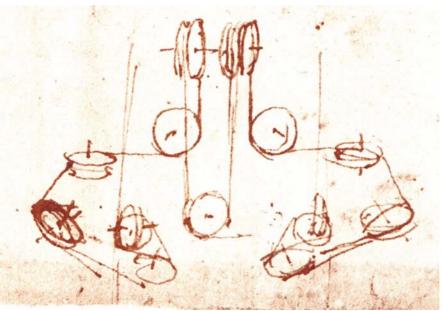
Fig. 3.20. CA, f. 216 v-b [579 r]. Italian Barbuta

on the top of CA, f. 366 v-a, b [1021 v] (Fig. 3.19) albeit upside-down. Two types of helmet are identified: a German Sallet (the two overlapping head figures) with laminated neckguard and visor pivoting high on the skull and an Italian burbuta, which resembles the Corinthian helmets of classical antiquity, as shown at the bottom of CA, f. 216 v-b [579 r] (Fig. 3.20).[15]

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[15] Cf. John Paddock and David Edge, *Arms and Armor of the Medieval Knight,* New York, Cresent, 1988, pp. 94–135, 141–142, 177–182. See also Charles Ashdown, *European Arms & Armor*, New York, Barnes & Noble, 1995, pp. 213–264. The British refer to the period of Leonardo's suit of armor (1430–1500) as the Tabard Period, so named for the surcoat or Tabard, which was the most persistent element in this period. The Tabard Period saw a great deal of technological progress due to the innumerable conflicts of the time. International conflict was the perfect setting for technology transfer, producing an international style. By the time Leonardo's suit of armor was designed, the entire body was enveloped and protected by a flexible, articulated suit. Selection of a suit of armor for the robot also had the advantage of a limited range of motion and flexibility that would simplify the task of animation.

Fig. 3.23.
CA, f. 216 v-b [579 r].
Cable system
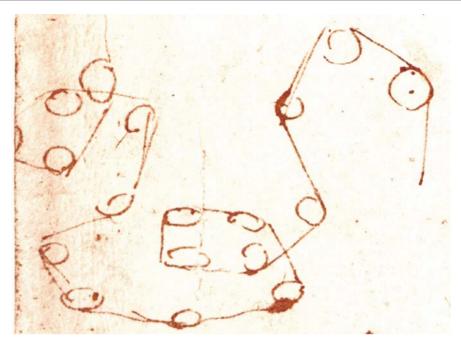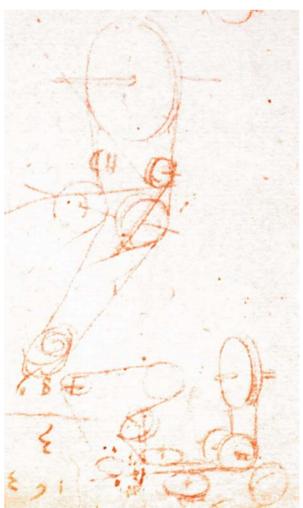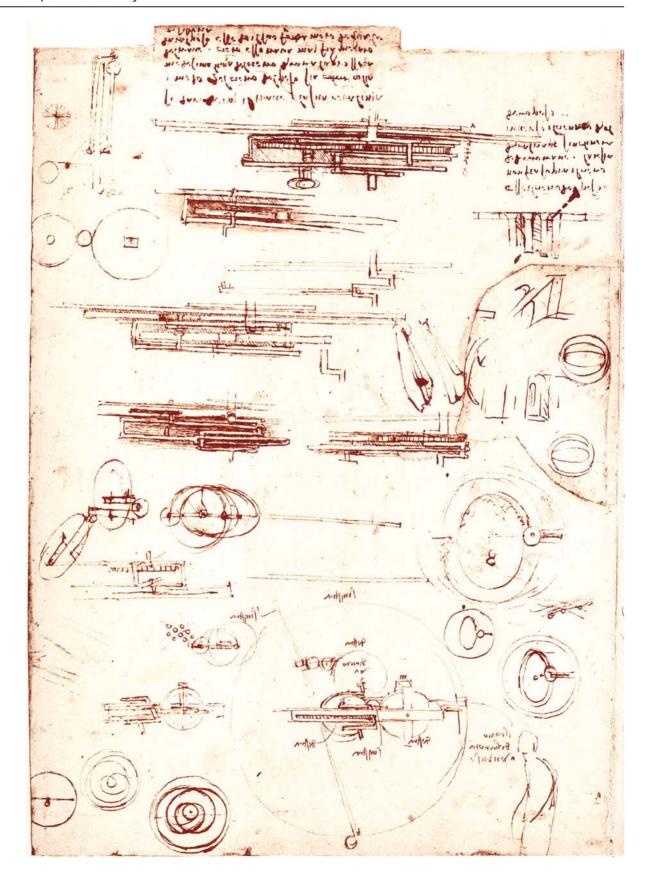
Fig. 3.24.
CA, f. 388 v-a [1077 r]
(right section). Cable system
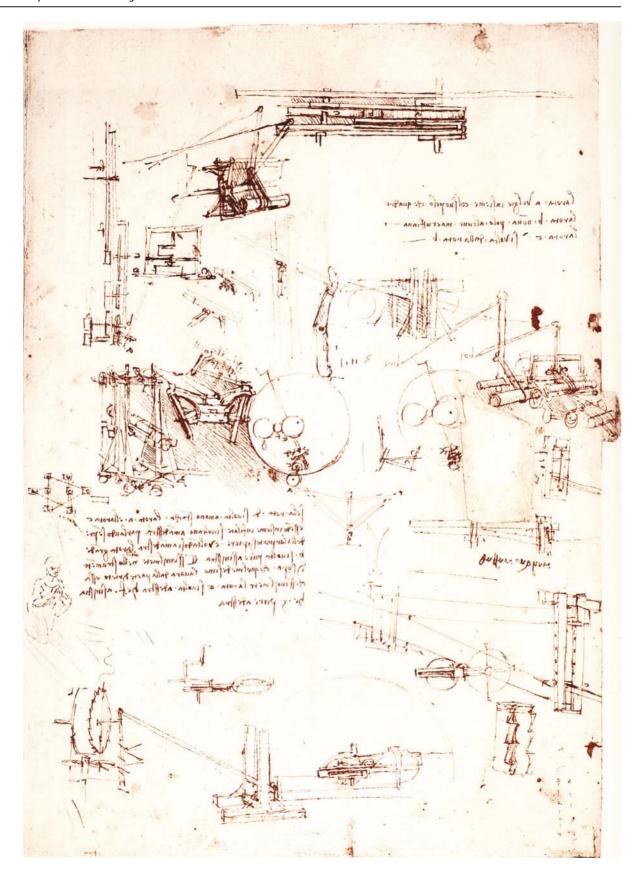
Exploded above the Knights torso and shoulder is an articulated joint, detailing the sliding rivet that allows a degree-of-freedom (Fig. 3.21). The cable system for the arms is shown in several details on CA, f. 216 v-b [579 r] (Figs. 3.22 and 3.23). The perspective view of the cable system includes a pair of vertical lines to indicate the width of the torso. These probably were drawn as an exercise to roughly size the suit of armor. Another cable-driven mechanism is shown in the right section of CA, f. 388 v-a [1077 r] (Fig. 3.24). In CA, f. 366 r-a (Fig. 3.25) dominated by planetarium studies is an intriguing figure with cables in the locations of arms (Fig. 3.26).

The mechanical arm, CA, f. 366 r-a [1021 r] (Figs. 3.27 and 3.28), is probably similar to the leg, in which a pivot pins the upper and lower limb for a single axis joint. It is located alongside the planetarium design. Behind the elbow are two connecting right angle lines, which indicate an access panel for fastening a cable to the elbow joint or for facilitating cable routing to the hand. An arm socket appears on the side of the right small helmeted head CA, 388 v-a [1077 r] (Fig. 3.4). The hand is roughly sketched with a thumb, corresponding to a gauntlet in having all four fingers enclosed as a group.
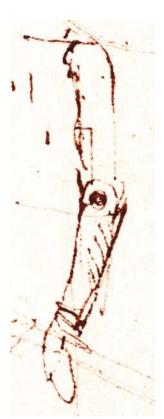
The idea that some or all of the sixteen missing folios of Madrid MS I, i.e. ff. 37–42 and 55–56, contained finished drawings of the biomechanical studies and the robots was a compelling one. Nearly every one of the technological sketches unrelated to the robot projects on the *Codex Atlanticus* sheets (e.g. the lifting and transporting devices, as well as the epicyclical mechanism for a planetarium) is found in highly finished drawings in the Madrid MS I manuscript.[16] On two facing pages of this manuscript, ff. 90 v–91 r, the legs for studying lifting forces are shown. This gives a direct indication what Leonardo may have had in mind for the robot (Figs. 3.29 and 3.30).

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[16] Concordance as given by Ladislao Reti in his edition of the manuscript p. 76 (CA, f. 36 v-a, b [102 r, 103i r] and r-a, b [100 r, 101 r]), (as in note 1 above).
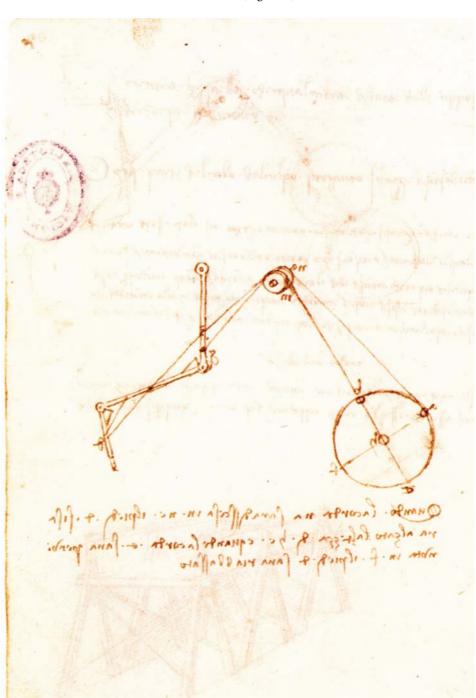
The gaps left by the missing pages of Madrid MS I may be filled by the comparative study of Borelli as discussed in Chapter I. Because of the great similarity of theme and organization, these studies are the perfect foundation to build a robot. Indeed, Borelli's plate V, fig. 7 (Fig. 3.31) could very well represent Leonardo's intention for the Robot Knight's leg CA, f. 366 v-b [1021 v] (Fig. 3.32). The angle of the knee and the ankle is exactly as in the completed leg. Partially overlapping the foot is the genouilli'ere (a segmented cover) to protect the knee. More knee drawings are shown along with the jaw mechanism in Fig. 3.33. Significantly, on the same folio a mechanical knee is drawn next to a human knee (Fig. 3.34).

Fig. 3.28. CA, f. 366 r-a [1021 r].
Mechanical arm

Fig. 3.29.
Madrid MS I, f. 90 v.
Mechanical leg
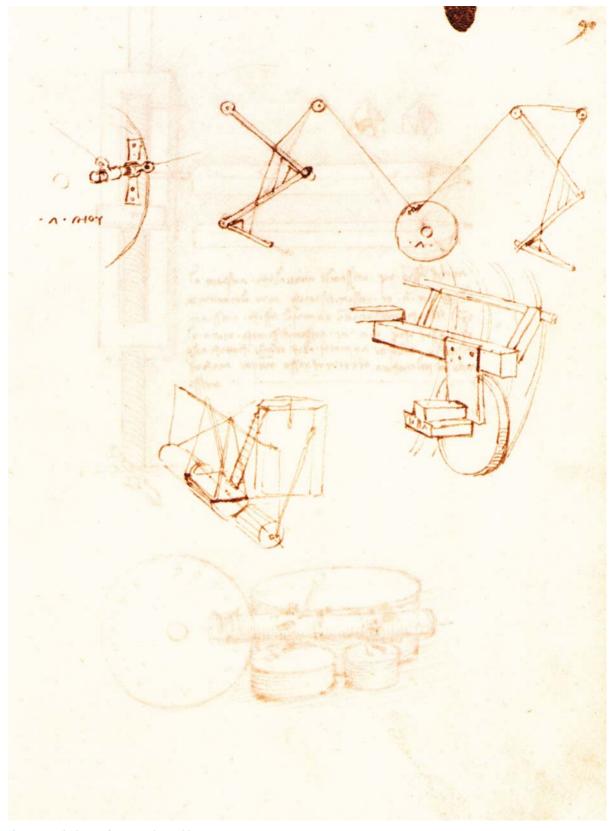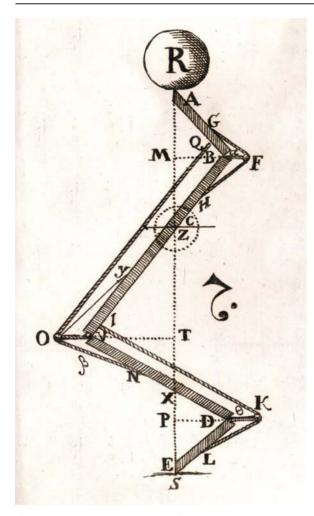
Fig. 3.30. Madrid MS I, f. 91 r. Mechanical leg

Fig. 3.31. Fig. 70. Borelli's leg, plate V, fig. 7

Fig. 3.32. CA, f. 366 v-b [1021 v]. Robot Knight's leg
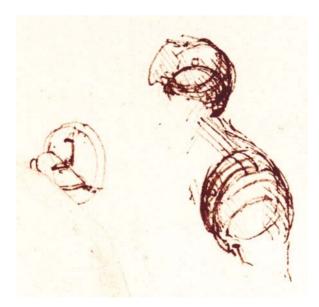
Fig. 3.33. CA, f. 366 v-b [1021 v]. Robot Knight's knee and jaw
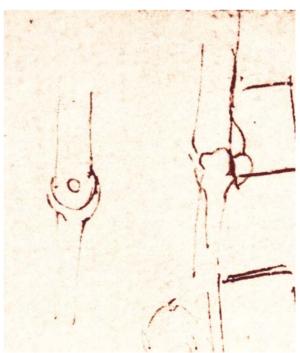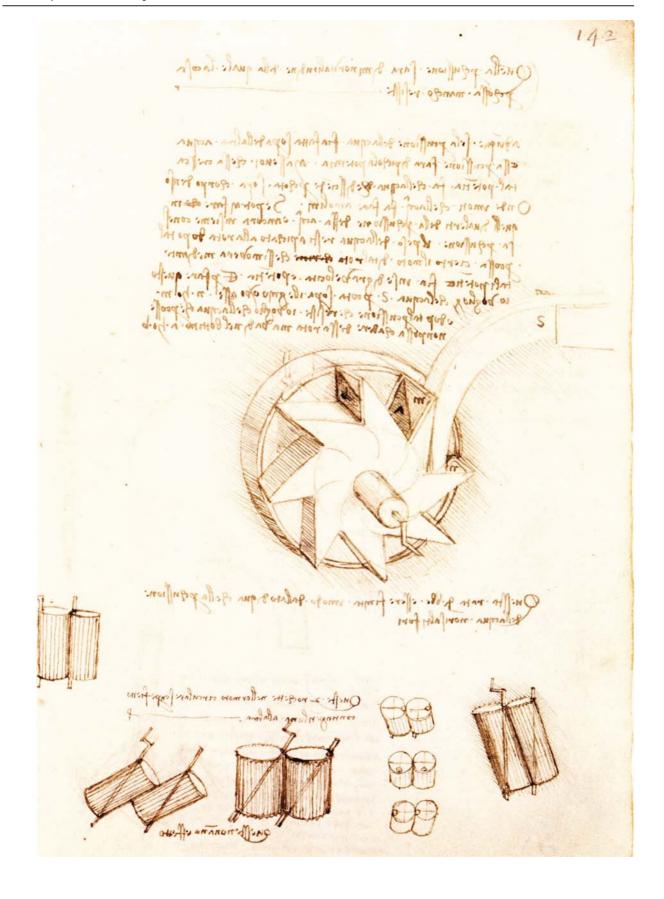
Fig. 3.34. CA, f. 366 v-b [1021 v]. Robot knee and human knee

Fig. 3.36.
Madrid MS I, f. 91 v.
Automated drum
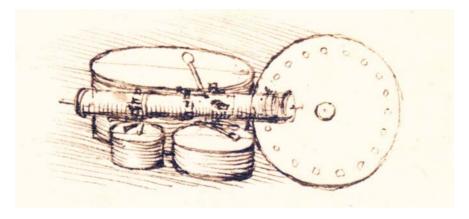
A water wheel with a description on f. 142 r of the Madrid manuscript (Fig. 3.35) is the same type as those later adopted by Bernardo Buontalenti, the architect of the Pratolino Gardens, and by Salomon de Caus.[17] This may have been the power source of the automaton. On Madrid MS I, f. 91 v (Fig. 3.36) following the diagrams of the leg biomechanical studies on the recto, are drawings of an automatic musical instrument which may have provided a military drum beat to accompany the knight as it made its appearance in a grotto. Paris MS H, the notebook of about 1484, also depicts numerous automated musical instruments.[18]

Reconstructions

To understand Leonardo's construction we must look to his teacher, Andrea del Verrocchio. According to Kenneth Clark, *Windsor Catalogue, sub numero*, "The deco-rated cuirass on the verso immediately suggest the workshop of Verrocchio, being of the same type as (though not identical with) that was worn by the two soldiers on the right of the silver relief of the beheading of St. John the Baptist in the Opera del Duomo, Florence."[19] In Milan, after 1482, he also came in contact with German crafts-men with expertise in armor construction.[20] Demonstrating his dissection knowl-

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[17] See the drawing by Heinrich Schickardt, c. 1600, recording the mechanism of the water organ for Mons Parnassus at Pratolino (LBS, Cod. Hist. 4, 148 b) reproduced in every publication on Pratolino, e.g. Luigi Zangheri, *Pratolino. Il giardino delle meraviglie*, vol. II, fig. 69, Florence, Regione Toscana, 1979. Marco Dezzi Bardeschi, 'Le fonti degli automi di Pratolino', in Alessandro Vezzosi (ed.) *La Fonte delle Fonti. Iconologia degli artifizi d' acqua* (proceedings of a colloquium held at Pratolino on July 14, 1984), fig. 30, Florence, Regione Toscana, 1985, pp. 13–24. See, in the same volume, pp. 35–43, Luigi Zangheri, 'Salomon De Caus e la fortuna de Pratolino nell' Europa dell primo Seicento', in particular fig. 3 on p. 36. See also Eugenio Battisti, *L'Antirinascimento*, vol. I, pp. 249–286, ('8. Per una iconologia degli automi'), text ill. on p. 270, Milan, Garvanti, 1989 (first edition, Milan, Feltrinelli, 1962).

[18] Emanuel Winternitz, *Leonardo da Vinci as a Musician,* New Haven and London, 1982, in particular on pp. 150–159, figs. 14–22. See also Richter Commentary, vol. II, pp. 215–216. For a through analy-sis and interpretation of their mechanism, see Marco Carpiceci, 'I meccanismi musicali di Leonardo', in *Raccolta Vinciana, XXII*, 1987, pp. 3–46.

[19] See the early drawings at Windsor, RL 12370 v, c. 1480. According to Kenneth Clark, Windsor Catalogue, sub numero, "The decorated cuirass on the verso immediately suggests the workshop of Verrocchio, being of the same type as (though not identical with) that worn by the two soldiers on the right of the silver relief of the beheading of St. John the Baptist in the Opera del Duomo, Florence". Compare also the famous profile of a warrior at the British Museum (Popham, pl. 129) also dating from about 1480. Cf. Mària G. Agghàzy, *Leonardo's Equestrian Statuette,* Budapest, Akadèmiai Kiadò, 1989, figs. 31 ff.

[20] 'Julio Tedesco' is mentioned in Forster MS III, f. I r, as having joined Leonardo on March 18, 1493 (Richter, §1459). He is also recorded in Paris MS H, ff. 105 r and 106 v, for mechanical work carried out for Leonardo in 1494 (Richter, §§1460 and 1462). Of particular interest is the note in Madrid MS I, f. 12 v, c. 1497: "Dice Giulio aver visto nella Magnja una di queste rote essere consummate dal polo m" (Giulio says to have seen in Germany one of these wheels become worn down by the axle m), in that it shows Leonardo's interaction with a foreign assistant.

edge, Leonardo built mechanical models of the muscles and joints.[21] His arm and leg-like designs for ornithopters attest to his full understanding of the mechanics of human and animal bodies.[22]

To get a picture of the overall exterior of the Robot Knight, I aligned the Knight fragments with the help of a photograph of Renaissance armor and had it redrawn (Fig. 3.37). Rivets on the sketch would even align with the photograph, indicating I was on the right track. At one time there must have been thick file folders containing beautiful, complete, assembled views showing the knight in multiple positions, as well as working drawings for fabrication. What have come down to us are the earliest conceptual doodles. But Leonardo, being Leonardo, naturally does even this very accurately and with surprising detail. Leonardo, in effect, saved his preliminary bar napkin sketches, perhaps along with more finished drawings in files. So although his final finished drawings were lost, it is possible to reconstruct his machines based on these fragments, stepping into his shoes as he put down his preliminary concepts. Indeed, as Pedretti has proven, entire lost sections of Leonardo's notebooks may be reconstructed in this way.[23]

Figure 3.38 shows my first reconstruction of the Knight's inner workings. The central drive pulley drives the looped cable through the arms to their drive pulleys. Idler pulleys maintain traction and direction of the drive pulley's direction. The legs may have been driven in a similar manner, as indicated by Madrid MS I, f. 90 v and 91 r discussed above.

However, in Madrid the legs are only capable of lifting, not pushing, most likely a part of a biomechanical experiment. To function for a robot, the legs require a second, antagonistically placed cable to protect the Knight from falling on his face, as shown in Borelli's leg studies mentioned earlier. The frame to support the pulleys and cables is the suit of armor itself, with integral bearings built into the elbows, knees, and shoulders. However, had Leonardo used a standard suit of armor, he would have likely built a skeleton to provide joints and support for the suit, as the frame is either missing or is unnecessary for a self-supporting suit of armor. Note that fifteenth-century armor is very different from the more familiar seventeenth- and eighteenth-century armor commonly on display in museums. Extremely thick and heavy, armor from the fifteenth century appears to be more like boiler plate from the few pitted examples I have seen.

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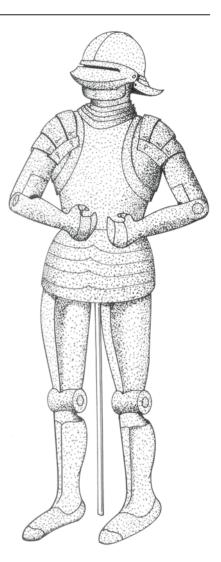
Fig. 3.37. Knight redrawn with Renaissance armor
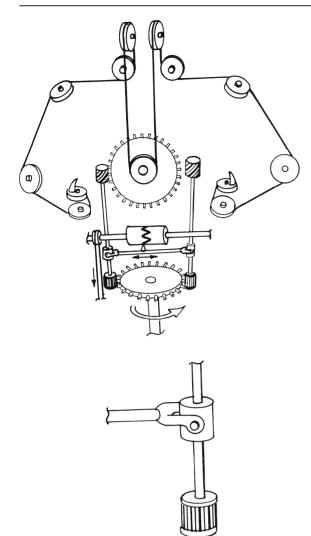
On January 5, 1997, the Sunday Cultural Supplement of Italy's major financial newspaper, *Il Sole-24 Ore*, carried Carlo Pedretti's full-page review of my essay "Leonardo's Lost Robot" that he had just published in his journal *Achademia Leonardi Vinci*.[24] This was more than a review. It included my first generation Robot Knight reconstruction. Perhaps because he was applying fifteenth-century intellectual property rules, Carlo felt unconstrained by international copyright laws and published it with-

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[21] See Pedretti's chapter on 'Anathomia Artificialis' as in note 1 above.

[22] The most striking example of this design is a highly finished drawing in CA, f. 341 r-c [934], c. 1508, reproduced in my *Robot Evolution* (as in note 1 above), fig. 1.13 on p. 17. Cf. Carlo Pedretti's *Codex Atlantics Catalogue* (New York, Johnson Reprint Corporation, 1978–1979), vol. II, pp. 193–194. Several preliminary studies are known, e.g. CA, f. 307 v-a [843], which includes details of the muscular legs of a nude standing figure.

[23] Carlo Pedretti, 1964. *Leonardo Da Vinci On Painting A Lost Book* (Libro A), Berkeley, and Los Angeles, University of California Press, 1964.

[24] See my "Leonardo's Lost Robot" in *Achademia Leonardi Vinci*, IX, 1996, pp. 99–110. Carlo Pedretti, "I robot secondo Leonardo", in *Il Sole-24 Ore*, no. 4, 5 January 1997, p. 23.

Fig. 3.38. First reconstruction of Knight's inner workings

out checking with me first. But as a quick and timely Machiavellian strategy, it was all for a good cause. It was to set in motion a chain of events that was to lead to my Vinci lecture of the year 2000.

As a first result of that press coverage I received a small contract in April 1997 from the prestigious Museum and Institute for the History of Science in Florence, directed by Paolo Galluzzi. This was for developing the CD-ROM for the Mechanical Marvels exhibit, which toured the world beginning at The World Financial Center in New York in October 1997, precisely at the site of the infamous Nine Eleven.[25]

On this, my first trip to Italy, I arrived in Rome taking in all the sights and sounds and caught the last train to Florence. The local train of Second World War vintage was quickly filled by natives grabbing all available seats, so I stood, talking to an Italian student who had traveled in the States. There was heated debate amongst the passengers about whether I should get off at Florence, and the discussion was ended when someone blurted out that if I didn't get off now, I would end up in Bologna!

Since it was now 2.30 A.M., my next problem was to find a cab in the dark, unknown city. To my eternal relief, when I left the deserted station and walked through a viaduct, I found cabs waiting. One of them whisked me to my little hotel, where I proceeded to wake the manager and crash on my little cot.

My first day on the job at the Museum began when I left my one-window garret hotel room, locking the door with a nineteenth-century skeleton key. As I walked down the ancient streets, through the Galleria degli Uffizi, I thought of how Leonardo himself may have walked these streets flanking the River Arno, nicknamed "the Blonde" for its yellow color caused by sediment.

At the Museum, I sat down with the draftsperson. Although we had a language barrier (she didn't speak English and I at that time didn't speak a word of Italian) we were still able to communicate though sketches. As we began to input my sketches, she quickly determined that my model was incomplete—how could the cables engage the driver pulley? With that sickening feeling that you have when arriving unprepared for a test, I headed out for escape and lunch. While ruminating on the problem, I hit upon the idea that Leonardo might be using idler pulleys to guide the cable around the drive pulleys, even though they were not shown in some of the most important figures. On my return to the museum, I seemed to verify this by plowing through all volumes of the *Codex Atlanticus* and found later examples of this treatment for canal locks in CA, f. 331 v-b [906 v] (Fig. 3.39), CA, f. 331 r-b [279] (Fig. 3.40) and 344 r-a [944 r] (Fig. 3.41). They depict idler pulleys wrapping cables around large drive pulleys.

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[25] The exhibition, as planned by Professor Galluzzi in Florence, was first taken to Paris with the title "Les ingénieurs de la Renaissance de Brunelleschi à Léonard de Vinci" in 1995–1997. It was turned into Mechanical Marvels: Invention in the Age of Leonardo for the American venue to include a section on Leonardo's robot entrusted to me. Exhibition organized by Finmeccanica Istituto and the Museo Di Storia Della Scienza, Florence. See the exhibition catalog Mechanical Marvels: Invention in the Age of Leonardo, pp. 234–235 and my reconstruction of Leonardo's robot knight in the companion CD of the same name, Giunti Multimedia, Florence, 1997.
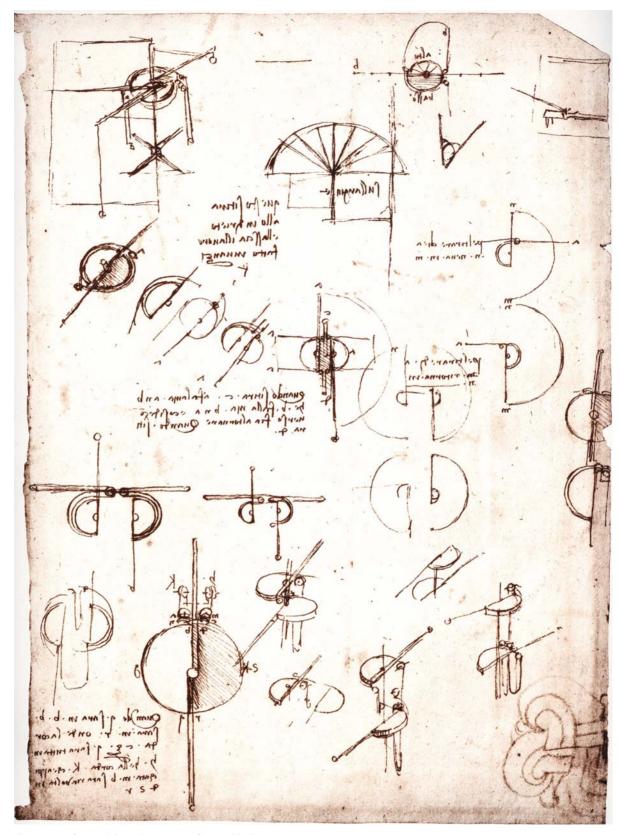
Fig. 3.39. CA, f. 331 v-b [906 v]. Treatment for canal locks
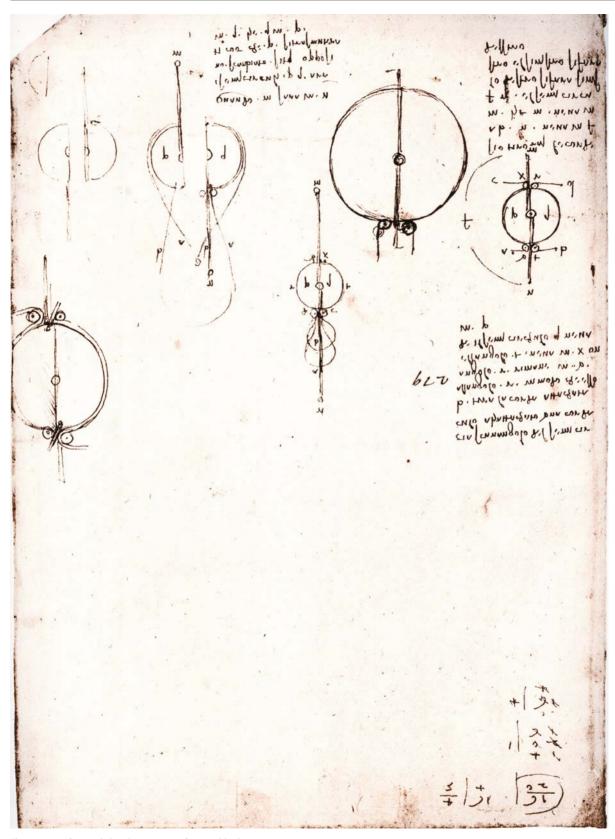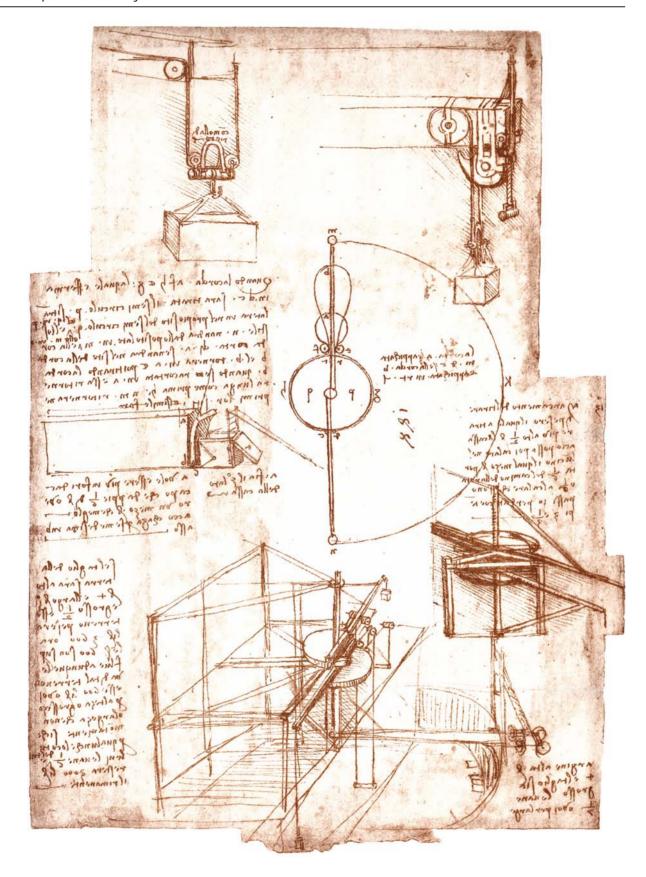
Fig. 3.40. CA, f. 331 r-b [279]. Treatment for canal locks
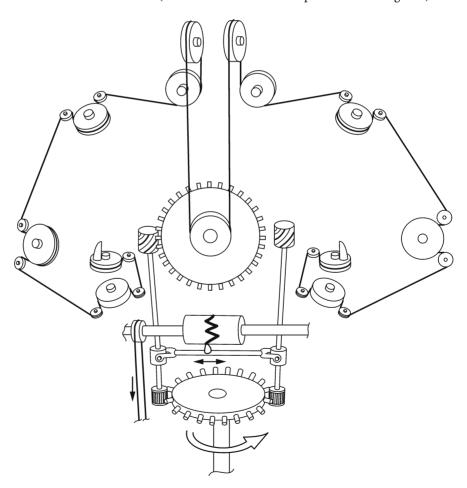
I then reexamined my preliminary drawings and reinterpreted them accordingly. I added the idler pulleys that I thought Leonardo must have left out. The single cable design would be maintained—gravity providing the restoring force to the arms. In this reconstruction the arms would always move in opposite directions i.e. one up and one down. Therefore the arms could have been made to beat a drum in a militaristic manner or to swing as the Knight walked forward. Possibly a clockwork controller drove the main drive pulley in the chest. I took a chance with this and added it to the reconstruction (Fig. 3.42). The clockwork mechanisms produced reciprocating motion so it seemed logical that it could drive the arms. Therefore it seemed to be designed for a reciprocating driver. For the first generation legs, I looked at the Madrid drawings.

Building Leonardo's Knight

In the spring of 2002, the BBC contacted me to film me building the robot Knight.[26] I flew to London November 2002 to build the Knight in a tight, compressed two weeks at the BBC Visual Effects workshop in West London. I modified the design somewhat to meet the needs and rigors of film work, making it simpler and more flexible. Also, a stock suit of armor was to be used in place of the dedicated suit that Leonardo indicated. I started by making a small Erector Set model in my basement, then began to design on paper while at the same time making a full size wood model of one side of the robot.

Forced now to resolve the drive train puzzle in actual hardware, I abandoned my first virtual reconstruction (the clockwork would have proved a daunting task) and

Fig. 3.42.
Second generation
reconstruction

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[26] BBC, Leonardo: program two, Dangerous Liaisons, airdate April 18, 2003.

began with my own, more comprehensive design, only to see it evolve toward Leonardo's as I strove towards a working full scale model. For economy, I chose a stock reproduction suit of armor purchased in advance and shipped to me for experimentation from England. The frame or skeleton design came from Madrid MS/Borelli and the upper body's ladder-like frame from Leonardo's many ornithroptor designs. Leonardo may have fabricated a custom suit of armor where he could have integrated pivots directly into the suit. The new BBC model would be fully functional, complete with cables and pulleys. Then, cringing at the thought of all the fees I would get from the airline for exceeding my weight allotment, I loaded nine cases, tool boxes, and a suitcase and boarded a jet to London. Still my design was not reconciled to Leonardo's drawings, although I have added more suspected drawings from the Codex Arundel, which at the time provided no further enlightenment.[27]

When I arrived, work began almost immediately with the help of a special effects expert Jamie Jackson-Moore who had recently built cars for the latest James Bond film. To meet the specification of the low ceiling in the grotto, I designed a base only four inches high. Housed in the base was a scissors-type car jack not unlike one Leonardo designed for his ornithroptor studies. The pulleys were originally fiberboard, but these broke and were replaced with harder beech wood. In my design the arms were to be driven independently by two separate cables that ran alongside the body, with idlers at the ankle, knee, hip and then up to the shoulders. They would terminate in pulleys driven by outboard driveshafts (Fig. 3.43). Not exactly Leonardo, but it was in his spirit, and it would guarantee a working model.

The mad rush to finish this took us into the late hours of the night, with reinforcements of additional technicians needed to complete the overwhelming amount of detail. One vexing problem was the cables, which had to be terminated to the various parts of the frame (Fig. 3.44). Not only was the crimping tool needed to attach the cables, which were not working well, but we also ended up with slack in the system. Lots of practice led to reliable crimps at last. Using my wooden model, I determined that in terminating the cable to parts of the frame instead of to the pulleys changed the radius and therefore the mechanics of the system. Adding an additional cable wrap around the pulleys fixed that.

When late night fast food was brought in from Burger King, I amazed the shop foreman with my ability to consume three burgers. A black track suit was pressed into service to fill in the voids backed by foam rubber. At the last minute, on the day of transport to the BBC's grotto, the armorer showed up and completed the skirt and arm details, greatly improving the Knight's appearance. Since the armorer used ancient techniques, we hunted down an anvil in a back room of the shop. Then, as I held the pieces, he riveted them in place.

The grotto was located outside London, at Painshill Park, Surrey, and was a perfect setting for the Knight. Once part of a great estate, the mansion still stands, the grotto under its bridge on a man-made lake. The lake is configured to pass via a tunnel

Fig. 3.43. Robot Knight reconstruction for BBC
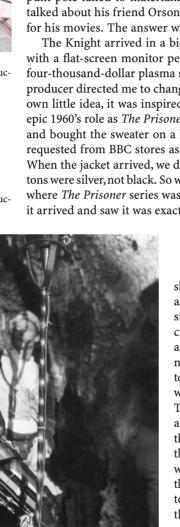
Fig. 3.44. Robot Knight reconstruction for BBC. View from side

[27] Mark Rosheim, "L' automa programmabile di Leonardo," *XL* Lettura Vinciana 15 aprile 2000, Florence, Giunti. See figs. 41–44

Fig. 3.45. Robot Knight reconstruction for BBC. Leg detail

Fig. 3.46. Robot Knight reconstruction for BBC
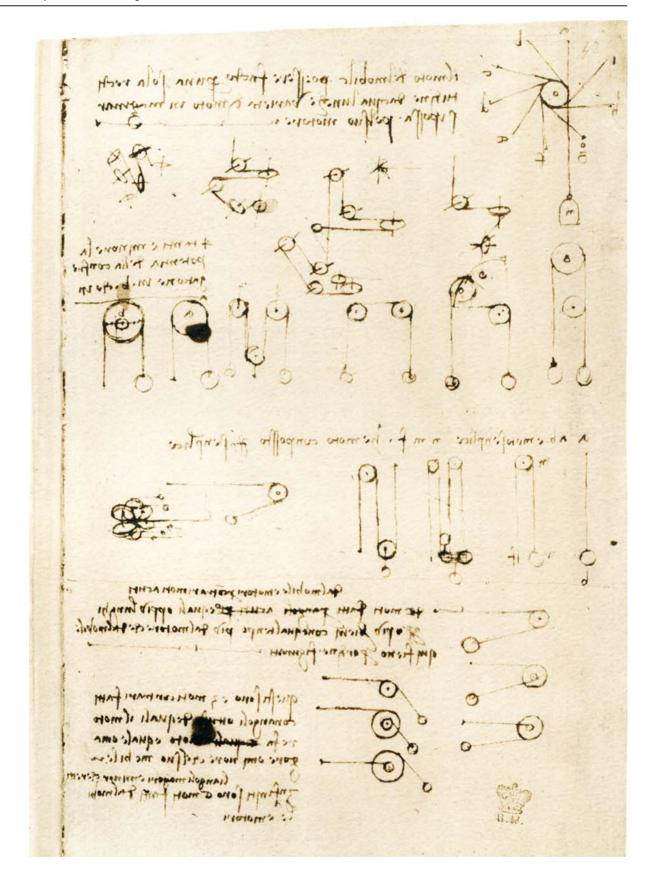
through the grotto, which has openings on two sides to form a canal through it. The canal is serviced by a parallel subterranean walking path. In order to reach the grotto, we had to take a punt, a traditional flat-bottomed boat. The producer, Oxford educated Tim Dunn, gave me a crash-course in punting with a fifteen foot-long punt pole. When we arrived at the lake, the assistant director George Williams was completing the onerous task of cleaning the punt of leaves and debris. I yelled to him, "What a connoisseur of edgework!" He held up his broom with both hands over his head, brandishing his implement in delight. Once in the punt, it was my job to transport Alan Yintob, the producer, narrator and head of BBC entertainment, by pushing a fifteen foot pole into the muddy bottom of the lake. To make my job trickier, the punt had a leak in its double-bottom construction and was wet and slippery. Thankfully, my nightmares of overturning the boat or knocking Alan into the lake with my punt pole failed to materialize. He even complimented me on my punting and we talked about his friend Orson Welles and why he had such a hard time finding funds for his movies. The answer was simple enough: Welles was hard to work with.
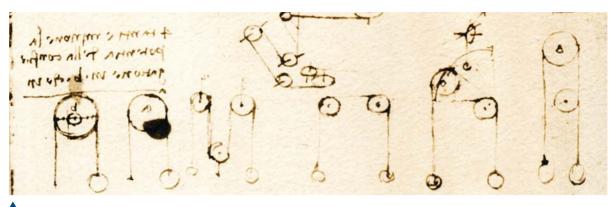
The Knight arrived in a big white panel truck and was set up in the grotto along with a flat-screen monitor perched on a shallow shelf in the cave. The thought of a four-thousand-dollar plasma screen falling and exploding was not pleasant. Then the producer directed me to change into my Cambridge boating costume for punting. My own little idea, it was inspired by my boyhood/adult hero, Patrick McGoohan, in his epic 1960's role as *The Prisoner*. The costume is a funny story. I had the pants already and bought the sweater on a late night shopping trip. However, the jacket had to be requested from BBC stores as we were told that it had to be exactly like the original. When the jacket arrived, we discovered the white piping was too narrow and the buttons were silver, not black. So we ordered one directly from the gift shop in Portmerrion, where *The Prisoner* series was filmed. Expecting perfection, we had a big laugh when it arrived and saw it was exactly the same as the one from BBC stores!

❖

The robot as reconstructed is controlled by three drive shafts protruding from the base (Fig. 3.45 and 3.46). These are manually rotated by cranks, one for each arm, and a single crank for the legs, which move in unison. The arm cranks thread their cables through the ankle, knee, hip and shoulder, terminating in a drive pulley. The shoulder motion is phased together with the elbow via a single cable to double the motion. It was starting to look like Leonardo with the weight of the arms setting the preload of the cables. The ankles, knees, and hips are phased together to produce a scissors-like motion. One of the lessons I learned is that the Robot Knight is heavy: the jack and frame strain to lift the load. This was partly a function of the 4-inch platform, which created a very short lever with which to push with the jack. A very modern automobile air-shock was added to help the lift the Knight. Clearly, this was an area of further research and improvement. Knowing Leonardo, he must have had a simpler and more elegant solution.

One of the interesting things about my reconstruction is that as the design developed, it became closer to what is shown in Leonardo's drawings. For example, in my reconstruction sketch, the arm cable originally looped to form a double. This later became single, as practical experience showed that, just as shown in Leonardo's notes, gravity was more than sufficient to provide a restoring force to the cable.

Fig. 3.48. Codex Arundel 263, f. 42 r.
Detail of pulley system

◄ Fig. 3.47.
Codex Arundel 263, f. 42 r
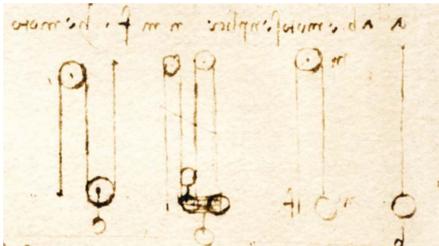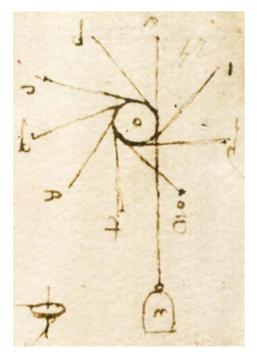
Fig. 3.49. ▶
Codex Arundel 263, f. 42 r.
Detail of pulley system

Fig. 3.50. Codex Arundel 263, f. 42 r.
Multi-cable system

Because of the incomplete and fragmentary nature of Leonardo's sketches, it was impossible for me at that time to tell with absolute certainty what Leonardo intended. It is clear that it was cable driven, but the complete drive train is unclear, as is the question of whether it had a controller similar to that of the Robot Lion.
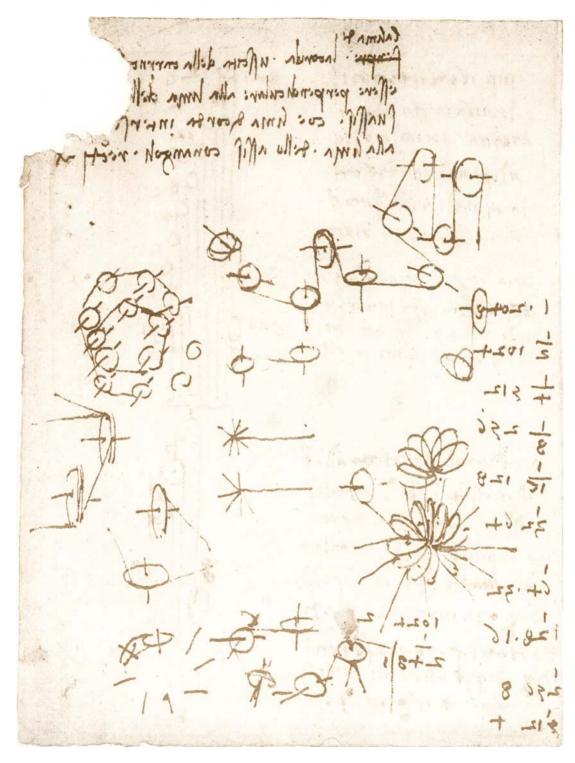
Only recently have I found the solution to the mysterious cable drawings in the *Codex Atlanticus* and more recently in *Codex Arundel*. Ironically, it would not be in Florence or London, but in my local St. Paul gym, while using the Cybex lateral pull-down machine, that I at last understood the upper body mechanics of Leonardo's Robot Knight. For when I looked at the cable system, I couldn't help but get the feeling I had seen it before (Fig. 3.22). There they were in the gym: the pair of flanking pulleys with the central pulley not rotated but *pulled* by a shackle connected to another vertical cable. It thus has dual function as an idler and as a drive pulley. As I pulled the two arm-like bars down, the central pulley went up, lifting the weights. So conversely, when the arms went up, so did the pulley. The arms could move independently for maximum flexibility. Eureka! I had it at last.

The central pulley shackle is what Leonardo didn't bother to draw in the bottom of CA, 216 v-b [579 r] (Fig. 3.22), and that is why it is so difficult to understand his intentions. One thinks of pulleys as something one rotates, but here it is suspended, free to be pulled down. In Codex Arundel 263 f. 42 r (Fig. 3.47) you can see Leonardo building his theoretical model. The upper portion of the page starts with several drawings of the upper body cable system. Below that, Leonardo builds his case from
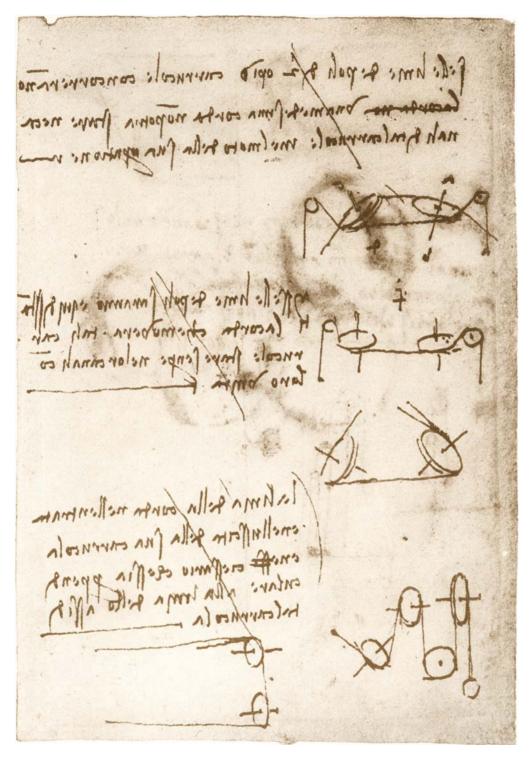
left to right, starting with a simple pulley with a weight (Fig. 3.48). Next comes the basic system, with the center pulley being pulled by a cable and the two weights representing the arms. To the right of that is a drawing with two weights over pulleys that have no center pulley. Below, a similar series of drawings are shown below from right to left (Fig. 3.49). At the bottom are studies of weights being pulled by single and double pulleys. At the top right of Fig. 3.50 is a weight pulling nine lettered cables
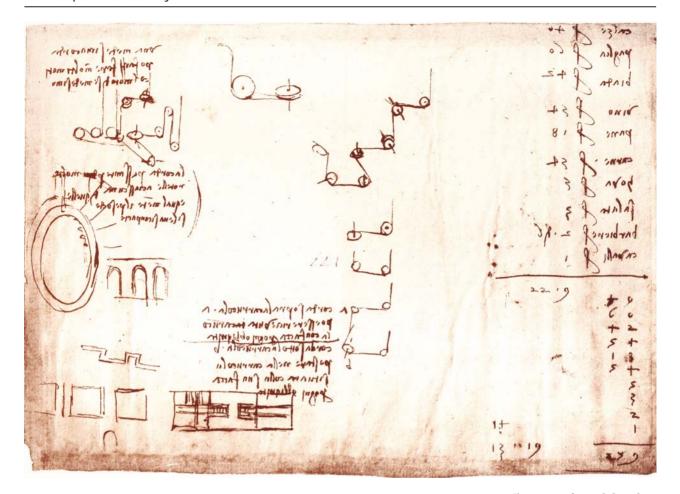
Fig. 3.51.
CA, f. 330 r-a [903 r]

that are perhaps connected to the multi-pulley device at the center left. Similar draw-ings are shown in CA, 330 r-a [903 r] (Fig. 3.51) and CA, f. 330 r-b [904 r] (Fig. 3.52). and CA, f. 134 r-b [369 r] (Fig. 3.53).

The reoccurrence of the multiple pulleys arranged in a ring and cables indicates that there might have been an even more complex cabling system planned. What function this may have is still unclear.

Fig. 3.52.
CA, f. 330 r-b [904 r]

Operation

Fig. 3.53. CA, f. 134 r-b [369 r]

The operation of Leonardo's Knight is a model of simplicity and elegance, solving several design performance problems with a simple cable system (Figs. 3.54 to 3.56).

A central cable pulls or releases the center pulley, which passes over the flanking idler pulleys. These idler pulleys could be used to operate the Knight's visor by simply adding some additional pulleys to the visor pivots. The cable then extends down to the pair of facing idler pulleys and then over the shoulder, elbow and wrist pulleys. The shoulder pulley shaft must be connected to the upper arm. The lower arm mimics the upper arm when the arm cable is pulled taut. One interesting performance characteristic of this cable system is its differential motion. For example, if one arm is pulled down, the central pulley will move up, compensating for the motion without disturbing the opposite arm (Figs. 3.56). When the central cable is pulled, it lifts and separates the arms, and when it is released gravity provides the load to lower them.
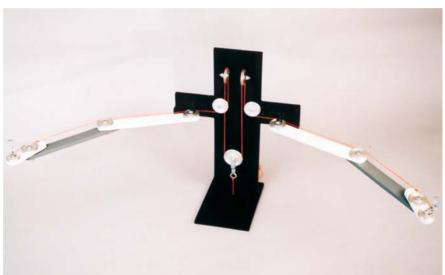
Another benefit of the single central cable design is that it simplifies the routing of the cable through or adjacent to the legs. Assuming that the arms are only operating when the Knight is standing, the cable could simply hang down behind the legs. It could be threaded through one of the legs, as I did in the BBC Knight, but I now feel it simply ran vertically down to the floor, either passing through the floor or via a pulley horizontal with the floor.

The center of CA, 216 v-b [579 r] (Fig. 3.57) offers an alternative cable system design which I only recently determined is for whole arm grasp when the two indepen-

Fig. 3.54.
Robot Knight cable system
arms together

Fig. 3.55.
Robot Knight cable system
arms apart

Fig. 3.56.
Robot Knight cable system
differential motion of arms
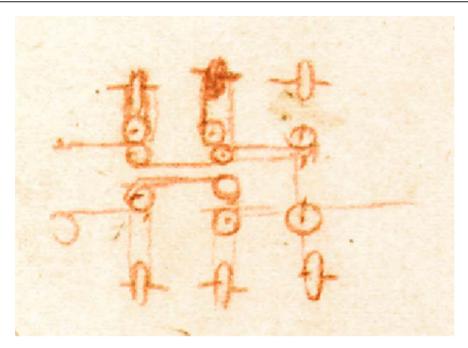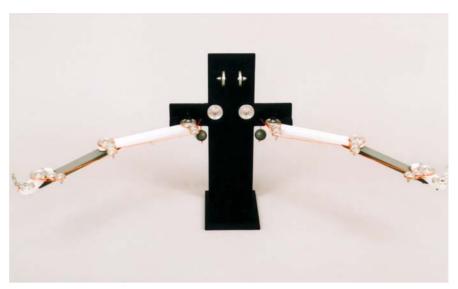
dent cables are pulled. Figures 3.58–3.60 shows my reconstruction. Two idler pulleys are added to route the cable around the shoulder, elbow and wrist. In my interpretation all of the pulleys are in the same plane and the idlers are smaller than the driver pulleys. Two balls are shown representing the counterweights of Leonardo. Interestingly, the top schematic left figure of CA, f. 216 v-b [579 r] (Fig. 3.61) has the same pulley count and terminates in ball counterweights as the above central figure. Figures 3.62–3.64 demonstrates my reconstruction. The question arise what purpose is the cable stretching between the two arms? Using the same reconstruction above I can only conclude that this is a method for ensnaring a culprit robotically. Pulling the two cables would not only pull the arms together in a hugging motion but increasingly shortens the cable between the hands until the hands touch. The problem of course would be how to get the loop and arms over the culprit. Perhaps the arms came down over the culprits head or through a hook and eye arrangement the arms linked up and connected the cable. Thus we have a hint of what Golpaja (discussed below) may have been inspired by.

Operation of the legs may or not have been a separate motion. The bigger question is how they were actuated. Although a jack could have been used, I find it hard to believe with all the leg cable systems in abundance that Leonardo could have resisted using them to drive the legs. For one thing, it produces a more natural and lifelike motion, as well as making viewing angles less critical. This was proven with the BBC Knight. Something simple, like the arms, seems indicated. Therefore, for lack of any contradictory evidence, I nominate my BBC design as the most likely candidate until further research indicates otherwise. A windlass could have provided the drive force. Regarding function of the Robot Knight, I believe a clue is offered by a notation in the *Venice Codex* from about 1520 by Benvenuto di Lorenzo della Golpaja, to which Carlo Pedretti first called attention in 1951 for its copies of unknown Leonardo inventions. Golpaja notes to himself:
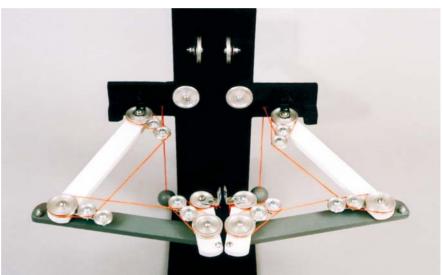
> To remind myself when I come to stay in Rome to make a wooden man who will stand behind a door, and when someone opens the door the wooden man goes to meet him with a stick to hit him on the head, or with a rope to grab him and tie him.[28]

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[28] Carlo Pedretti, "Invenzioni sconsciute di Leonardo da Vinci in due codici inediti del XVI secolo," in *Sapere, XVII*, 1951, pp. 210–213, reprinted in the author's *Studi Vinciani*, Geneva, Droz, 1957, p. 23–33.
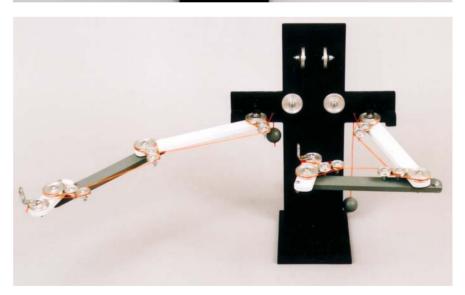
Fig. 3.58.
Alternative cable system
reconstruction arms apart

Fig. 3.59.
Alternative cable system
reconstruction arms together

Fig. 3.60.
Independent motion of arms

Fig. 3.58.
Alternative cable system
reconstruction arms apart

Fig. 3.59.
Alternative cable system
reconstruction arms together

Fig. 3.60.
Independent motion of arms
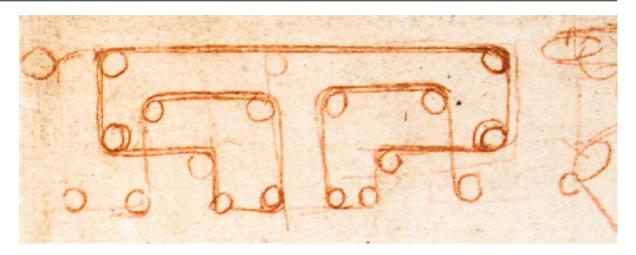
Here we have an application that the Knight fits most admirably. It is almost like something one would find in an old time amusement park, a piece for the scary haunted mansion or tunnel of love—or a labyrinth, which was the 16th century equivalent. The Knight would be excellent at grabbing someone with its arms in a bear hug. The differential motion would automatically compensate for one of the arms being out of place. In the simple cable version it is not particularly dangerous, to escape the Knight's grip, one would simply have to overcome the weight of the arms. Perhaps the visor would rise, revealing a hideously contorted, sculpted face. And like the cart it would be controlled remotely via one or more cables.

However, one thing can be said with certainty about the lost drawing(s) as works of art—they must have been beautiful beyond compare and perhaps were the centerpiece of Madrid MS I. Someday the missing drawings may surface. They could have been stolen at any time, perhaps by Borelli himself, or even in recent times. They could have been separated and rebound in a separate book now hidden in some cavernous and clandestine library where at this very moment it is being gazed upon by some unknown collector. It could well be the book we know as Madrid MS I was mutilated by unknown hands, or that Leonardo himself rearranged the sheets, for he mentions on a sheet of anatomical studies from around 1508–1510 at Windsor, RL 19009 r: "Arrange it so that the book on the elements of mechanics with its practice shall precede the demonstration of movements and force of man and other animals, and by means of these you will be able to prove all your propositions."
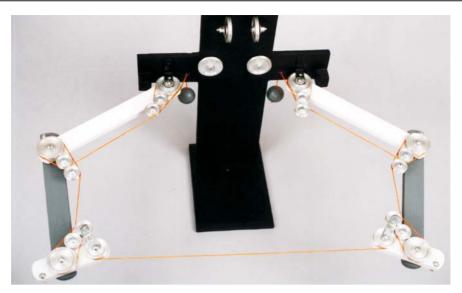
Leonardo's Robot outwardly appears as a typical German-Italian suit of armor of the late fifteenth century. Built into its chest is an elegantly simple differential pulley/cable drive system. The cables exit the robot from the back or base. Power for the robot to move its arms and stand or sit came from manual operation or perhaps a waterwheel.[29]

Perhaps the great mystery surrounding this lost robot of Leonardo can be summed up by the master himself in the giant scrapbook known as the *Codex Atlanticus*. In the sheets for this project, we read an incomplete sentence with which Leonardo tried out his pen: "Tell me if ever, tell me if ever anything was built in Rome …"[30] Leonardo may be expressing his frustration and anxiety about a project near and dear to his heart that because of external pressures could not be born.

Fig. 3.61. CA, f. 216 v-b [579 r]. Second alternative cable system

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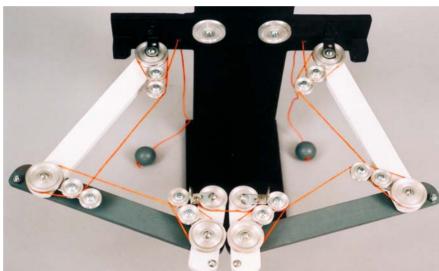
[29] This seems to be implied by the sketches in Paris MS L, f. 28 v, and CA, f. 164 r-a [444 r], though the context shows that Leonardo is analyzing the mechanical problem of pulling a weight uphill. Cf. Reti, op. cit. (as in note 12 above), p. 82–83, fig. 15.

[30] Cf. Richter *Commentary*, note to §1360, where all such sentences are reported, though never again with a reference to Rome.
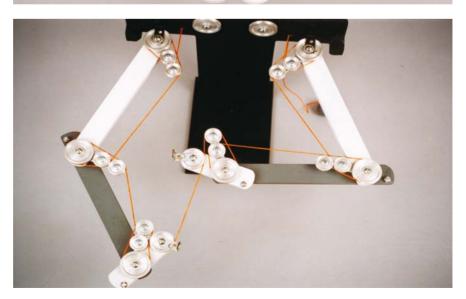
Fig. 3.62.
Second alternative cable system
reconstruction arms apart

Fig. 3.63.
Second alternative cable system
reconstruction arms together

Fig. 3.64.
Differential motion of arms

Leonardo's Bell Ringer
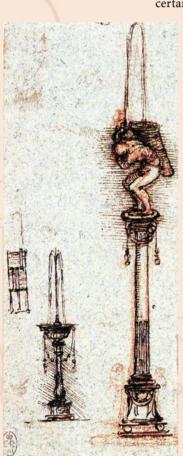
Leonardo's Bell Ringing Jacquemart (c. 1510) represents the last and most highly developed of his automata. In what follows, we see how Leonardo's project to design a hydraulic clock that rang the hours relates to earlier renditions of hydraulic devices, fountains and water clocks.

Ancient Models

Leonardo's major source of information about hydraulic devices in antiquity would certainly have been Heron of Alexandria of the first century, an author made known by the humanists, and whose *Book of Pneumatics* greatly appealed to him, particularly for the so-called Heron Fountain. The latter was first described by Alberti, illustrated by Andrea del Verrocchio, and applied many times by Leonardo in his hydraulic devices, such as in the beautiful table fountains at Windsor (Fig. 4.1). Heron's *Book of Automata*, best known in Bernardino Baldi's 1589 edition, includes a number of theatrical devices as well.
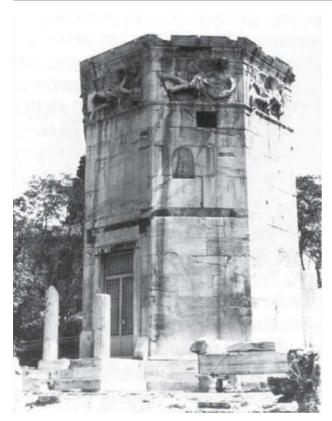
There is another great hydraulic achievement of antiquity that must have appealed to Leonardo. This is the Tower of the Winds, located in the Agora in the center of Athens (Fig. 4.2). Constructed by Andronicus Kyrrhestes of Macedonia during the Roman period in the second quarter of the first century B.C., it was one of the few structures from antiquity to have survived intact. Built of marble and octagonal in shape, it is 43 feet (13 m) tall. It was a marvel of antiquity, boasting complex sundials on top; a frieze on each of its eight sides; and according to one ancient account, a weathercock at its pinnacle in the form of Triton, son of the sea god Poseidon; clepsydra; a planetarium and possibly automata. Leonardo was certainly acquainted with the Tower of the Winds through Vitruvius and other sources[1]. In the middle 1960s, Derek De Solla Price reconstructed the clepsydra under a grant from *National Geographic* magazine[2]. It represents the state-of-the-art of ancient water clock technology, or "horologion"—an "hour indicator." The following description of the clock is based on Price's reconstruction.

Fig. 4.1. Table fountains, Windsor, RL 12690

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[1] Derek De Solla Price, *Gears from the Greeks: The Antikythera Mechanism. A Calendar Computer from ca. 80 B.C.*, New York, Science History Publications, 1975, pp. 51–62. As Price relates: "The Tower of Winds, located in the Roman Agora in the heart of Athens, was built by Andronicus Kyrrhestes of Macedonia about the second quarter of the first century B.C. It was a monument designed in accord with the science of the day with an especially complicated sundial on each face of its octagonal tower, a wind vane and a frieze of the gods of the prevailing wind above that, and a whole series of marvelous astronomical and probably other showpieces inside. It was a sort of Zeiss planetarium of the classical world".

[2] Derek De Solla Price, Athens' Tower of the Winds. *National Geographic,* CXXXI, no. 4, April 1967, pp. 586–596.
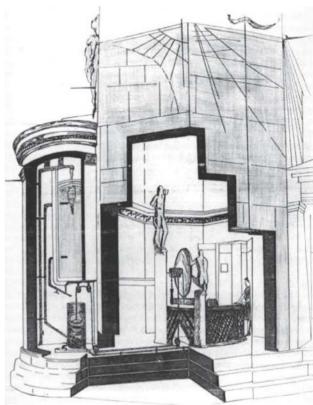
Fig. 4.2. Tower of the Winds
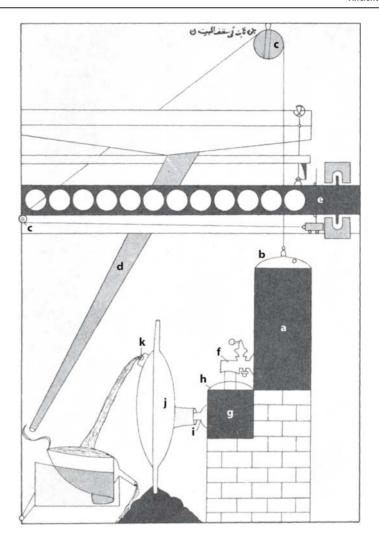
Fig. 4.3. Tower of the Winds mechanism

The Tower of Winds Water Clock was designed along the lines of Ctesibus about the middle of the third century. It appears to be the first to introduce a float into an inflow vessel. In Ctesibus' design, an indicator rod is carried by the float which shows the time by its position above the vase. A large tank (Fig. 4.3) is fed constantly by an outside pipe from a brackish spring located high on the Acropolis.[3] The lower pipe pours a constant stream of water that slowly raises the float in the smaller container. When fully raised, the float releases a chain, which is wrapped around a pulley and terminates in a counterweight. Gradual descent of the counterweight rotates the clock disc. The clock disc, Price speculates, was made of bronze and depicted "a model of the universe moving in harmony with reality. Among Andromeda, Perseus, and the figures of the zodiac, a golden sun, pegged into the proper hole for the time of year, moved behind a wire grid which indicated the hours of day and night and the lines of the horizon and meridian". The wire grid, perhaps held by Atlas or Hercules, is accented by three fountains fed by the middle overflow vertical pipe running along the same channel as the chain.

Every two days, the attendant would reset the sun peg into its new location. No doubt the same attendant would reset the clock every 24 hours by emptying the small tank via a square opening in the floor, starting afresh the clockwork universe. Thus started, the bronze clock disc rotates clockwise, as have all of our clocks for over 2 000 years.

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[3] Derek De Solla Price, op. cit. in note 2 above, p. 591.
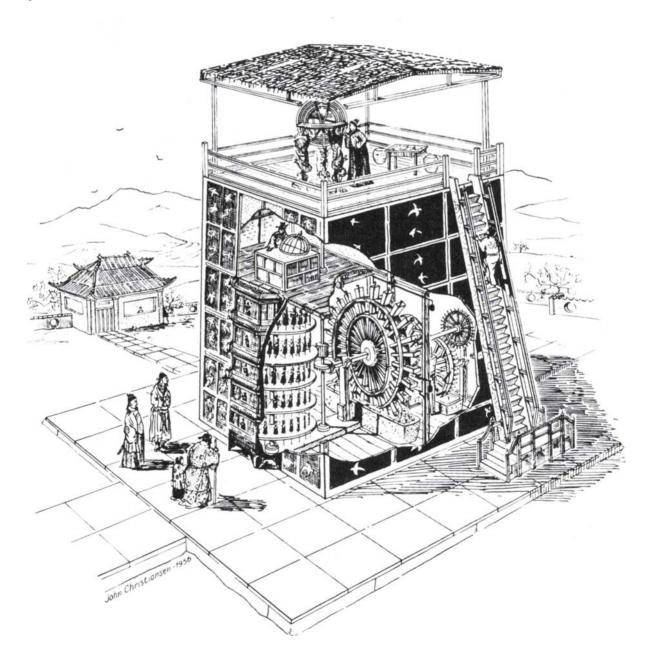
The Hellenistic tradition of water clocks and automata was preserved after the fall of the Roman Empire by the Arabs (Fig. 4.4). An entire book of these devices was written by al-Jazarī in the thirteenth century, whose *Book of Knowledge of Ingenious Mechanical Devices* illustrates and describes several clocks with automata, some of extreme complexity, utilizing the same siphons, floats, valves and reservoirs that Leonardo would later use.[4] In one mechanism, a reservoir tank is filled with water *(a)*. A float *(b)* suspended by a cable over pulley *(c)* slowly sinks as the water flows out of the reservoir. The cable slides the pointer *(d)* across the 12 holes indicating the hour. The water pours out of valve *(f)* filling a smaller container *(g)*. In it a second float *(h)* has a ground stopper which automatically turns off the tap above it when the smaller container is full. When the float sinks, the valve is re-opened. Therefore, the water in *(g)* flows under constant pressure via pipe *(i)* located near the base of *(g)* into the circular shaped container *(j)*. The water exits through an overflow port *(k)*, which should be at the same level as *(g)* at its highest position (it is illustrated incorrectly). By rotating the vessel *(j)* along the axis of pipe *(i)*, the rate of outflow could be varied and thus the length of the hours.

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[4] Donald R. Hill, *The Book of Knowledge of Ingenious Mechanical Devices by Ibn al-Razzaz al-Jazari*, Boston, D. Reidel Publishing Company, 1974, pp. 42–50.

Chinese influences may have played a part in the technological development of Arab fountains. Su Sung (1020–1101) was a Renaissance man hundreds of years before the European Renaissance. Astronomer, mathematician, diplomat, and naturalist, he produced a classic *Pen Tshao Thu Ching* (*Illustrated Pharmacopeia*) on pharmaceutical botany, zoology and mineralogy. A consummate civil servant who mastered the available technical knowledge and applied it to the benefit of the state, Su Sung wrote another classic, *Hsin I Hsiang Fa Yao,* or *Horological Engineering.* His astronomical clock tower (Fig. 4.5) was not created by trial and error but was the product of careful written technical proposals followed by small wooden models and then a full-scale one against four types of clepsydra. Only after four years of trials was the casting completed. This explains why the complex drivetrain worked and was able to rotate the armillary sphere of some 10–20 tons and a bronze celestial globe 4.5 feet in diameter.

Fig. 4.5. The Su-Sung astronomical clock tower c. A.D. 1090

Fig. 4.6.
Fountain at Rimini

The 11-foot diameter great water wheel was driven by water from a constantly fed tub that supplies water to the paddle wheel buckets. The buckets are of particular interest as they were articulated in such a way as to form the first escapement mechanism—hundreds of years before escapements were reinvented in the West—with an accuracy not obtained again until end of the sixteenth century.[5] As Needham states in his classic *Science and Civilisation in China*, "Its peculiar interest lies in the fact that it constitutes an intermediate stage or 'missing link' between the time-measuring properties of liquid flow and those of mechanical oscillation".
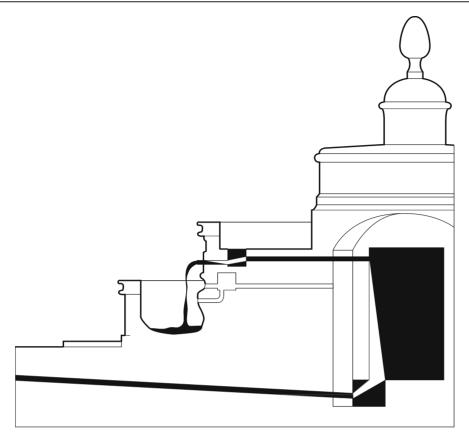
A bronze armillary sphere was located on the roof, and the celestial globe was recessed in a cabinet on the floor directly below, creating an artificial horizon. They were also powered by the waterwheel via gearing. Automata, rotating on a five-level turntable, appeared in openings of the pagoda-like façade and performed by striking bells, gongs, or perhaps even drums announcing the night watches and their divisions. The turntables were six to eight feet in diameter, suggesting the jacks, which were clothed in different colors, were quite large.

A major source of inspiration for Leonardo was the Pigna Fountain (Figs. 4.6–4.8) at Rimini, on the northeastern coast of Italy. Leonardo fell in love with the harmony of the waterspouts radiating out of its diameter when he passed through Rimini's medieval Piazza Cavour in 1502. He even wrote a note to himself about it: "let a harmony be made with different falls of water, as you saw at the fountain of Rimini on August 8, 1502".[6] During the reign of Paul III (1534–1549), it was crowned with a statue of the prelate's likeness, but this was replaced in the nineteenth century by the "Pigná" (pine cone) that gives the fountain its present name. Of ancient Roman origin, the fountain was originally fed by aqueduct. In 1543 it was damaged by fireworks set off in the tub to celebrate the high prelate whose likeness it bore. Giovanni Carrari from Bergamo restored it, forming its present shape while still reflecting the original, ancient plan. Recently restored,[7] it appears to have inspired Leonardo's project for a building-size water clock or clepsydra powering a bell-ringing Jaquemart.

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[5] Joseph Needham, Science and Civilization in China, vol. IV: 2, London, Cambridge University Press, 1965, pp. 435–481.

[6] MS L, f. 78 r, Richter, §1048.

[7] Carlo Pedretti, "Rimini. Una fontana per Leonardo", introductory text to the exhibition catalogue *Leonardo. Machiavelli. Cesare Borgia. Arte storia e scienza in Romagna, 1500–1503,* (Rimini, Castel Sismondo, 1 March–15 June 2003), Rome, De Luca Editori d'Arte, 2003, pp. 11–21.
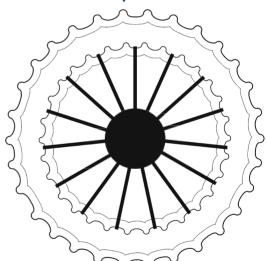
Fig. 4.8. Fountain at Rimini top view section
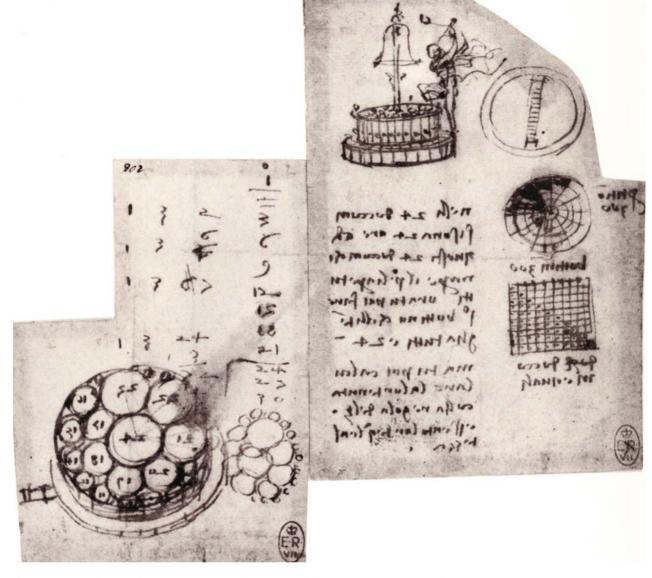
Leonardo's design antedates automata that would appear in grottoes in the late sixteenth and early seventeenth centuries, and may have been their inspiration.[8] The celebrated park of Pratolino near Florence, full of such technological wonders dating from the 1570s and much admired by visitors and technicians from all over Europe, has been shown as a possible example of Leonardo's ideas first applied to garden architecture. His projects for the suburban villa of the French governor of Milan, Charles d' Amboise, included a mechanical bird for a theatrical performance.[9] The fashion of garden technology and water displays was soon to spread all over Italy, particularly to Rome, as if to recreate the wonders of classical antiquity. Such amusing water displays can still be seen all over Europe.

Leonardo's bell-ringing Jaquemart appears on several sheets of the *Codex Atlanticus* and in the *Windsor collection*, dating from about 1508–1510, the time of Leonardo's activity as an

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[8] Michelangelo Buonarroti the Younger, *Desicione delle felicissime nozze della Cristianissima Maesta' di Madama Maria de' Medici Regina di Francia e di Navarra*, Florence, Giorgio Marescotti, 1600, p. 10, describes a mechanical lion produced at a banquet and acknowledges the Leonardo antecedent. Cf. Pedretti, *Leonardo architetto*, Milan 1978 (English edition, London 1986, and NY 1991), pp. 319–322, figs. 506 and 507. For an overview of late sixteenth-century robotic devices applied to a natural setting, see the special research conducted by Professor Marcello Fagiolo of the University of Rome, *Natura e artificio. L'ordine rustico, le fontane, gli automi nella cultura del Manierismo europeo*, Rome, Officina Edizioni, 1979, particularly for the second part on pp. 137–258 on 'Il giardino: la grotta, l'acqua, gli automi'.

[9] The play staged might have been Politianus' *Orpheus* or an adaptation of it. Cf. Pedretti, *Leonardo architetto*, Milan, 1978 (English edition, London, 1986, and New York, 1991), pp. 293–295. See also Richter *Commentary*, note to §678.

Fig. 4.9. Jaquemart from Windsor, RL 12716 and 12688

architect in the service of Charles d'Amboise in Milan. Shown in Windsor, RL 12716 and 12688[10] (Fig. 4.9), the Jaquemart is an example of a robotic device for telling time, ringing every hour on the hour and striking the bell with the corresponding number of hours. One version may have been designed to fit within its own custom building. If constructed on such a large scale, it would be similar to the great clock tower in the Piazza San Marco, in Venice, where two giant, roof-mounted human figures have been striking the single bell with mallets hour by hour since 1497 (Fig. 4.10). During the writing of Madrid MS II, f. 55 r, in 1503–1504, Leonardo describes a water organ "with many concords and voices" and his plan to make it portable as well. Both of the above influences would form the foundation of Leonardo's Jaquemart, or Bell Ringer.

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[10] In addition to a fragmentary sheet at Windsor reconstructed by Carlo Pedretti with fragments 12716 and 12688, the bell ringer project has survived in several sheets scattered throughout the *Codex Atlanticus*, e.g. f. 65 v [20 v-b], which in turn is the parent sheet of Windsor fragments 12480 and 12718 r. Cf. *Leonardo da Vinci, Fragments at Windsor Castle from the Codex Atlanticus*, Carlo Pedretti (ed.) London, Phaidon, 1957, pp. 38, 41, and pl. 2. See also my paper "Leonardo's Lost Robot", in *Achademia Leonardi Vinci, XI,* 1996, pp. 99–110, in particular p. 100 and fig. 2.

In the mid-fifteenth century Florence Leonardo's teacher Andrea del Verrocchio constructed what must have been an early inspiration to his talented pupil. The story is related by Vasari (III. 375):

> It is also by him the *putto* for the clock of the New Market place [in Florence], a figure with articulated arms, so that, by raising them, it strikes the hours with a hammer—a device that was then much admired as a beautiful and whimsical thing).[11]

In February 2003 I began to reconstruct Leonardo's Bell Ringer by gathering up the material that scholars-historians rather than engineers have attempted to identify as possibly related to it. And so I went back into Leonardo's notes for unidentified material. With the surviving operational descriptions, I worked out how I would solve the problem myself. This I call the "top-down approach". My second method is to try to fit the pieces of the puzzle together more or less on their own. This "bottom-up approach" is the way scholars and engineers have traditionally attempted to solve the riddle of Leonardo's notes on projects. The problem with this is the extremely fragmentary nature of the legacy—the gaps are too big to be filled in.

To close the gaps, I apply my "mortar", derived from the "top-down approach". In thinking like Leonardo I'm aided by my engineering, history, and art background, which utilizes sketching in notebooks to solve problems. Having a natural talent for complex, three-dimensional visualization, I also have little formal schooling, so I do not have the typical engineering background of my age with its mathematical theory emphasis and loss of craft practices. This is one way in which my thought processes

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[11] Vasari. *Lives of Seventy of the most Eminent Painters, Sculptors and Architects by Giorgio Vasari*, vol. II, p. 255. New York, Charles Scribners's Sons, 1896. Cfr. *Achademia Leonardi Vinci*, X, 1997, pp. 273–274.

are different from those of scholars and engineers. For better or for worse I am a Renaissance man. My own sketching was based on Leonardo's technique so when I work the same problem I produce similar preliminary drawings to his. In short, I am his student. Also, through the study of Leonardo's drawing style, I "weigh" his drawings based on the level of detail in the execution, recurrence, etc. and assign them a value accordingly. I also keep in mind that Leonardo's solutions are simply brilliant, requiring the minimum number of components to get the maximum number of functions, so I try to look for the simplest, most elegant solution, which forces me to abandon complex, "Rube Goldberg" contraptions in favor of straightforward designs.[12] The problems Leonardo was solving, together with the many obstacles to understanding his solutions, means that I am not able to reconstruct his intentions in one attempt; the Robot Knight, for example, required three before I was satisfied with the results. Having the luxury of making models rapidly accelerates the process.

Of course, it is critical that the final reconstruction is just that, a reconstruction of Leonardo's intention, not a Mark Rosheim invention. So throughout the reconstruction process Leonardo's drawings are constantly cross-checked against my progress until full agreement is reached.

The Bell Ringer is unique in that, compared to the other unreconstructed projects by Leonardo, it has a large amount of related text with which to work. Although most of the text would prove to relate to an earlier version of the device, it proved critical in understanding the more advanced version.
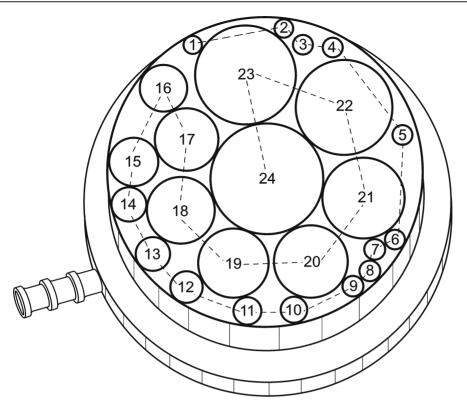
Pieces of the Puzzle

I began my hunt for the Bell Ringer by collecting all the drawings related or suspected to be related to the Bell Ringer. Of course I utilized the references as mentioned in my tomes, but I also paged through all twelve elephant folio volumes of the Codex Atlanticus with little more thought to the effort than I would if paging through a paperback book, allowing interesting images to present themselves to my eyes. For the task of reconstruction, I needed to have these images at my fingertips, not easy to do with the Codex Atlanticus, in which the drawings are scattered and also occur on both sides of the pages. In need of a way to view the pieces conveniently, I hit upon the idea of scanning the images from the elephant folios into my scanner. This was awkward—they're not called elephant folios because they're lightweight—so I laid my scanner up-side-down on the relevant pages and scanned them into my computer. The machine protested with a grinding of gears, but once the pages had been scanned, I could zoom in or out, rotate, and print.

At the same time, I started sketching the basic design and daydreamed how I would solve the problem myself. As in the Robot Knight, I had little more to go by than groupings of figures with notes regarding dating. Many of the drawings had been already identified long ago. Even Carlo could offer no help, not even a hint—I was in uncharted territory.

Two pages that have survived started me on my path. Windsor, RL 12688 that Carlo had first shown to have been originally joined to RL 12716 (the Bell Ringer fragment), depicts a large cylinder containing 24 tightly packed containers. These cylinders are labeled 1 through 24 and are arrayed in a convoluted spiral formation

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[12] CA, f. 206 v-a [549 v], c. 1497: "When you wish to produce a result by means of an instrument do not allow yourself to complicate it by introducing many subsidiary parts but follow the briefest way possible, and do not act as those do who when they do not know how to express a thing in its own proper vocabulary proceed by a method of circumlocution and with great prolixity and confusion": Quando voi fare uno effetto per istrumento, non ti allungare in confusione di molti membri, ma cerca il più brieve modo; e non fare come quelli che non sapendo dire una cosa per lo suo proprio vocabulo, vanno per via di circuizione e per molte lunghezze confuse".

(Fig. 4.11). The cylinders become progressively larger, with the largest and last, 24, in the center of the figure. Faintly drawn lines radiate out from the center of the figure. A perspective drawing of the lower cylindrical portion forms the base and corresponds to the upper left figure of 12716. What might be a segmented supply or drain pipe protrudes from the base on the left. To the right of the main figure a cruder version is sketched. Above the figures are columns of numbers relating to the "rule of three" which Leonardo used to determine the diameter and capacity of the containers. The rule of three relates to the formula for the volume of a container: $V = \pi r^2 h$.
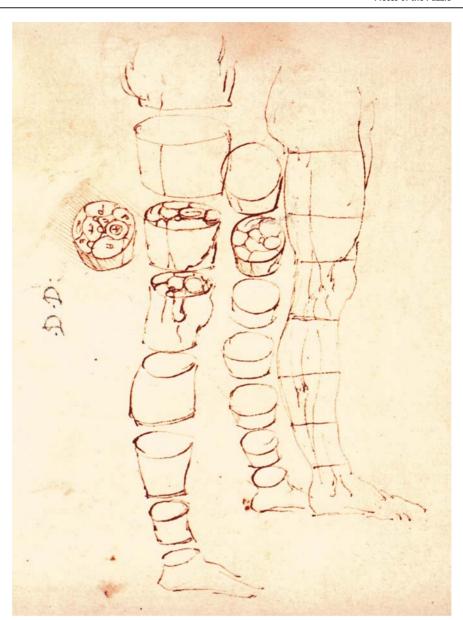
In Windsor, RL 12716, the upper figure, drawn in perspective, shows the entire system comprising a bell on a post attached to a stepped cylindrical base. The base is proportioned similarly to the fountain at Rimini and includes what might be radiating water spouts, represented by small circles around the diameter of the upper cylinder. However, if this were the case, there would be approximately twice the number of spouts as the Rimini fountain. The circular target like figure (lower right) bears a striking resemblance to the top view of the Rimini fountain and appears to have fourteen radiating lines corresponding to the Rimini supply lines. To the right Leonardo writes "Partitions 300" and below it "Bottini 300." Significantly, a grid like drawing on the bottom is labeled "Bottini all a-like."

A humanoid figure—The Ringer—is climbing the fountain. His right leg is bent to place his foot on the upper level. Like a knight about to make the down-stroke with his sword, the ringer's left arm is wound up over his head. As Carlo Pedretti has noted,[13] the ringer's hammer cannot strike the bell by simple rotation of the base as the hammer and bell are in separate planes.

The text of 12716 reads: "In 24 containers there are the 24 hours, and the one of these 24 containers that opens the first then opens all of them. Now you can make a

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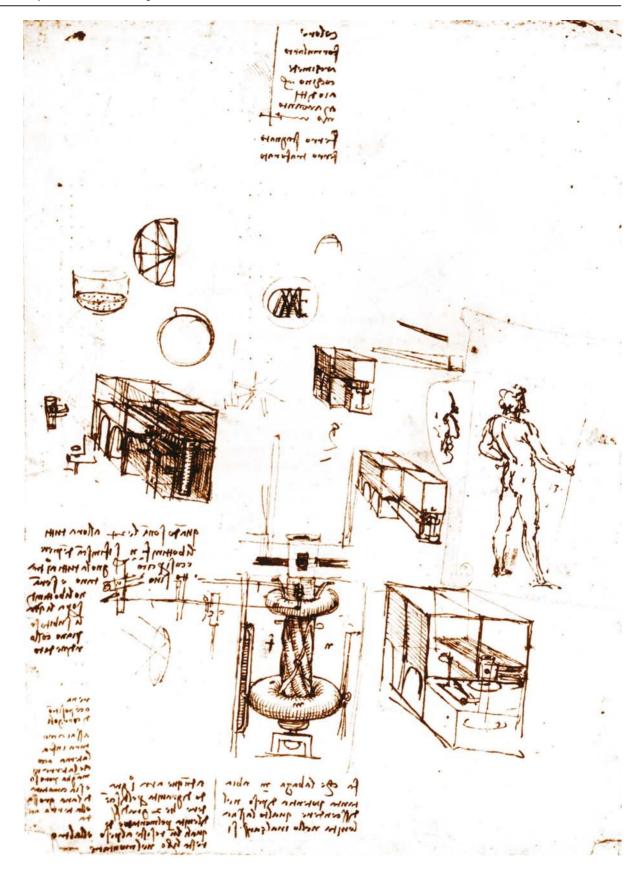
[13] Personal communication.

drum-like well ["bottino"] that keeps all the 24 containers". Then Leonardo adds, "but you can calculate their volume by the rule of 3 since they are of equal height". In other words, Leonardo has designed a system with 24 containers, which allows him to pack them in a drum-like well. The 24 containers hold the "24 hours." They all have equal heights, so he can easily calculate their volume by the rule of three. As Leonardo put it, the 24 chambers, each of a different capacity, empty their water in a predetermined sequence. The sequence is initiated by the first container. Compactness is a goal: as in a comparable cross-section view of the muscles of a leg as shown in early anatomical drawings at Windsor, RL 12627 v K/P 4 v (Fig. 4.12).

Other drawings depict the components and provide hints on their operation. Let us begin with f. 20 v-b [65 v] of the Codex Atlanticus as reconstituted by Carlo Pedretti with two Windsor fragments back in 1957 (Fig. 4.13). The upper left figure depicts a perforated bowl-shaped object in the bottom of a cylinder, possibly a strainer. To the right of it are geometrical studies. Several building sketches with float mechanisms appear in the center and below. Similar structures appear under the face and statue

at right. A detailed drawing in the lower center depicts the actuator/valve assembly (Fig. 4.14). Upper and lower floats (Leonardo calls them "*baga*)" are shown mounted on a helical column. A lower float is guided by pair of flanking guide rods mounted to the inside wall of the cylinder. A valve stem with an upper and possibly two side ports are shown with a container sketched above them. The text describes the operation:
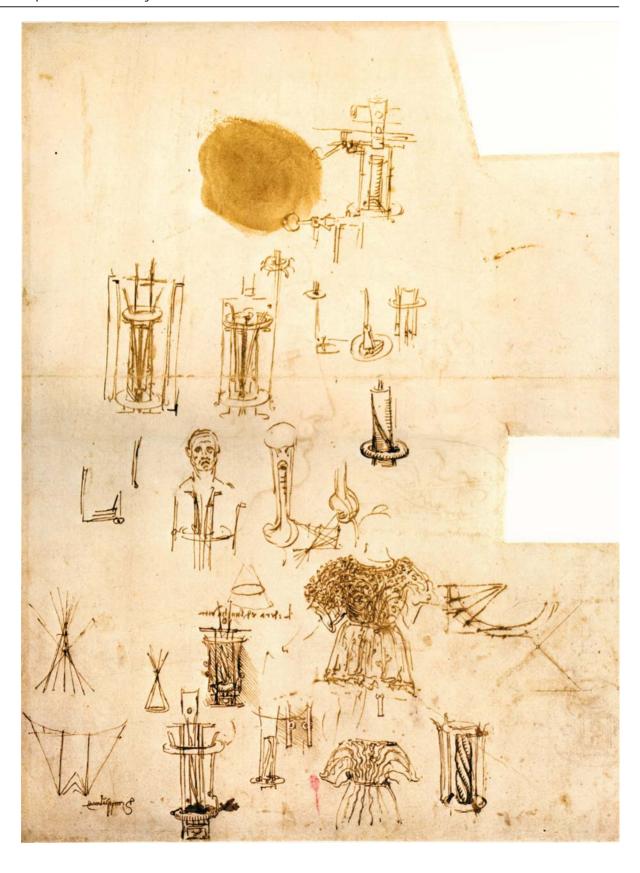
> When the 24th hour strikes, then all the containers can come to be filled up, and so through the "spiral siphon" ["cicognola"] they all empty themselves at once and shut those above, which get to be filled up according to the preestablished order.
>
> See to it that the float [the "life saver"] may be so much heavy in descending as it is light in raising. Thus it will have to have one degree of weight in its descent and two of levity in its ascent. One of them resists to the weight and the other is left free in rising.

From this, I could understand the basic operation—the float rises when filling— but what was the upper float, the "spiral siphon", and that diagonal link across the helix? A sequence is described, but what does it mean? Does the "preestablished order" refer to the sequence in which the containers are filled? I focused on what was before me—the mechanism—and turned to the closest similar drawing that might help me to understand it.

Fig. 4.14.
CA, f. 20 v-b [65 v] with Windsor
fragments RL 12480 and 12718
(after Pedretti 1957).
Actuator/valve assembly

Fig. 4.16.
Windsor, RL 12282 v K/P 125 r.
Actuator/valve assembly

In Windsor, RL 12282 v K/P 125 r (Fig. 4.15), several variations are shown of actuator/valve mechanisms. The top figure (Fig. 4.16) shows a multi-port valve with a float release latching mechanism actuated by a small float on top. This is for releasing the "*baga*" or donut shaped float at the base. Below this figure, several drawings show the related linkage release mechanism of CA, f. 20 v-b [65 v] (Fig. 4.17). They are particularly significant because they explain why, for example, there is a diagonal link overlaid on the helix drawings with a pivot in the center. It is as if Leonardo were drawing it in as an afterthought rather than planning for it by showing the figure in section and showing it clearly. That is why you see the diagonal link—a minimal reminder Leonardo makes for himself. Also, if you look very carefully at the same drawing, to the bottom right of the helix you can just see the companion release tip.

It is also interesting that the scissor-like linkage of the "bottini" is very similar to scissor-like linkage used as cam followers for the cart in Chapter II. That linkage is driven by rotating cams to turn the cart's steering wheel. Indeed, this linkage, also used for control, does the same job for the "bottini" transferring motion from the "upper baga" to release the lower "baga" and thus producing valve stem rotation. See page 157 and Fig. 4.51 below for further information.

In the center of Windsor, RL 12282 v K/P 125 r head/neck and a portion of shoulders are shown superimposed on the actuator/valve mechanism (Fig. 4.18). To the right is a human stomach and esophagus (Perhaps Leonardo is drawing an analogy between the "baga" rising up and the action of the esophagus muscles. These sketches may

Fig. 4.19.
Windsor, RL 12282 v K/P 125 r.
Helix formed by perforated tube

also be clues for the automata perhaps using the same valve/actuator technology. To the right (Fig. 4.19) is a helix formed by a simple perforated tube. Below a drawing of a costume are geometrical studies possibly relating to the helix angle of the screw.

I could now see how the actuator/valves operated. Two floats are slipped over the hollow shaft the lower one engaging the helical groove with two lugs. Both floats are in their lowest positions. The upper container is full and the lower container is empty. The lower float is held in place by the tong release mechanism. Water fills the container to the upper float. The upper float lifts and trips the tong release mechanism releasing the lower float. It rises rapidly through the water rotating the helix and turning the valve above it. This valve releases the water stored in the upper container, simultaneously shutting off the water to the lower container and opening a passage for the water to pass to the next unit. Now that I had the basic operation of the two floats, including the snap action timer function, my attention turned to how they were used as a system for the Bell Ringer hydraulics.

Folio 362 v-a [1011 r] of the Codex Atlanticus (Fig. 4.20) is an important drawing for understanding the operation of the Bell Ringer's hydraulics. The upper group of figures shows a series of valve stems with containers above them (Fig. 4.21). Below these figures the text reads:
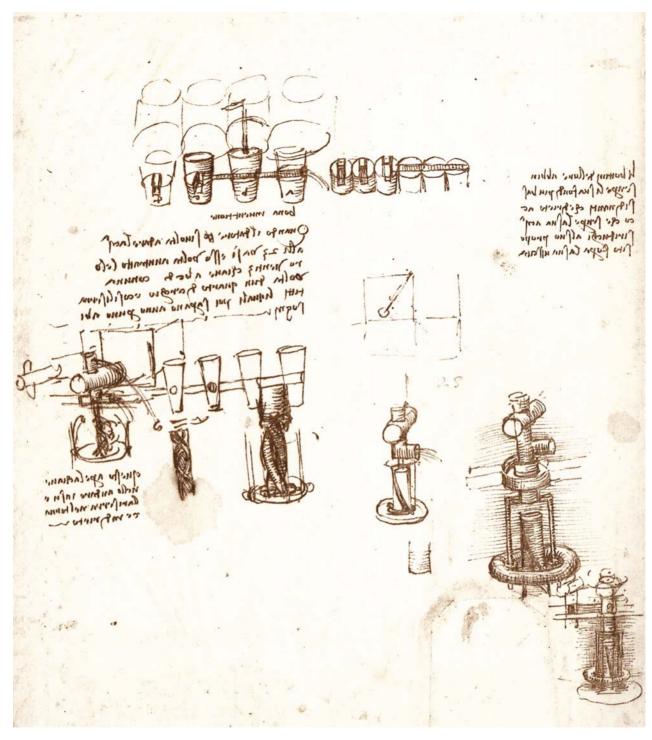
The containers of the hours must always have their bottoms lower on the front side and higher on the back, so that the water will always be able to flow away from the containers.
Vases with water: a b c d- good invention.
When the bringer turns himself to give water at the 23 vases, the bringer turns rapidly their 23 keys a b c d, which turns for a quarter of arc [90 degrees], and so it closes them all. Then they open one by one when needed.
Device for automatic opening and closing:
This opens the key while going up and closes the key when it comes back.

Fig. 4.20. CA, 362 v-a [1011 r]. Hydraulics

From this we can see the construction of the "container of the hours" and the operation of the "Bringer" and how it functions with the 23 keys, the word Leonardo uses for valve stems. Also, we learn that turning the keys 90 degrees serves to close them. Drawn in the middle of the page and continuing down to the right are what I now see as early versions of the actuator/valve assembly, which automatically stops and starts the flow of water through it and the container above.

Fig. 4.21. CA, 362 v-a [1011 r].
Valve stems with containers

But what was the "Bringer?" Folio 343 v-a [943 r] of the Codex Atlanticus (Fig. 4.22) shows an array of valves with vertical pipes, additional valves and valve stem arrays. To the right is an illustration of water pouring into a vessel. The "Bringer" is shown in the central, elaborately detailed figure (Fig. 4.23). The right is an overview of the "Bringer": Below, left is the "Bringer's" faucet in multiple positions. The bottom figures are variations on the latching mechanism that restrains the "baga" or donut shaped float. The wildly complex "Bringer's" operation is detailed in the last paragraph of this sheet. Almost a robot in itself, the Bringer's main float is unlatched when water reaches to the level of the upper float. It immediately begins to rise and trips a valve mechanism to its right and then starts rotating. It begins to engage levers on the left, turning the faucet-like spout to various fill points, which are the "Container of the Hours"—the containers that power the alarm bell.
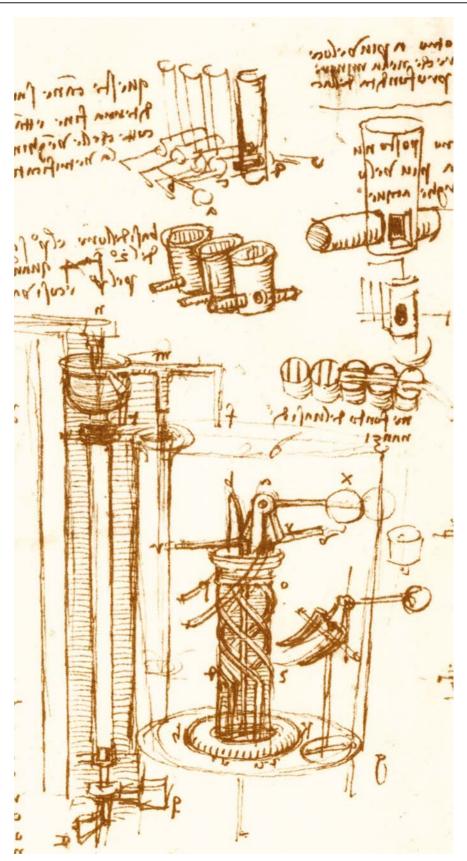
The text is interesting for its construction and operational descriptions. The upper notes relate to wineskins, so it maybe be deduced that this sheet belongs with CA, f. 373 v-b [1042 r] (Fig. 4.32), which shows leather bags rather than actuator/valves as key components. I believe that the "leather version" represents an earlier conception, for the wineskins lack the durability of the final actuator/valve concept and may be a more literal representation of Leonardo's thinking about the mechanism. Indeed, all of the following Leonardo sheets in this section may be linked either to references to leather or to the "Bringer", making them all part of this particular design effort.

Another passage on CA, f. 343 v-a [943 r] gives an interesting construction detail: "These pipes will be made of thin clay and cooked for very long, until they become glass". Operational information is also given: "Vases of the hours. The first opens and then the water of the second, when it opens, move through the first and this way it keeps going". Leonardo then poses the question of how to close them and answers
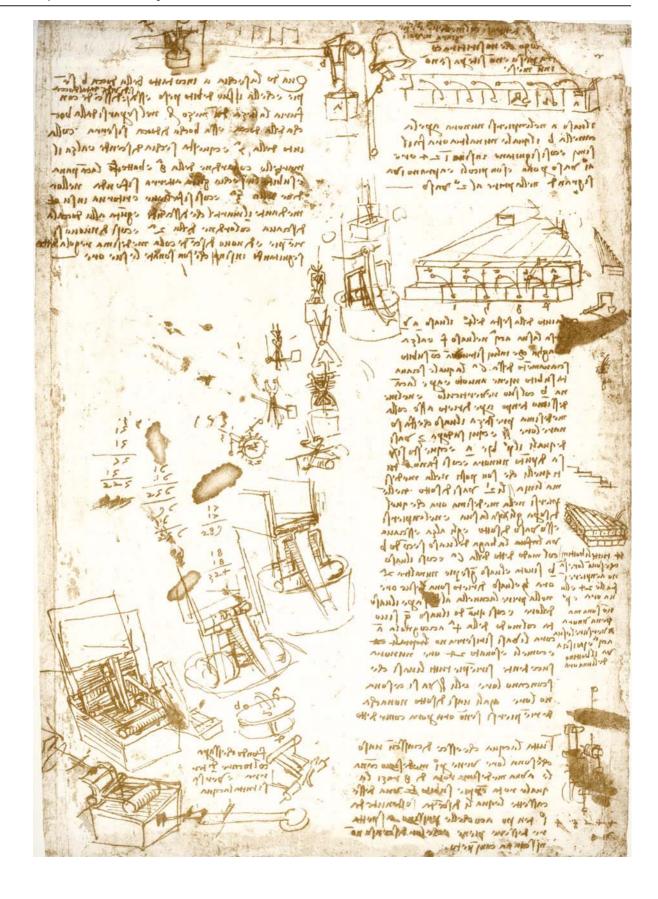
◄ **Fig. 4.22.**
CA, 343 v-a [943 r].
The bringer and accessories
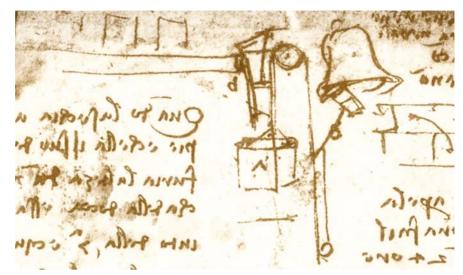
Fig. 4.23.
CA, 343 v-a [943 r].
The bringer and valve array
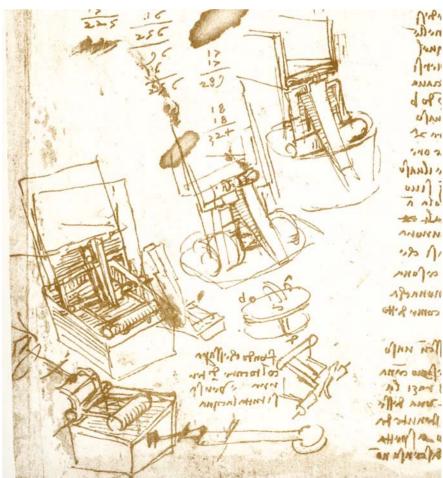
himself: "But then think about what it will be that will have to close them. It will be the 'baga' that each of those has inside". On f. 343 r-a [941 r] of the Codex Atlanticus (Fig. 4.24), the top figure shows an actuation scheme for the bell. When the bucket fills, a hammer controlled via the pulley and cable system hits the bell (Fig. 4.25). Lower figures (Fig. 4.26) relate to a container that, when filled with water, raises a

Fig. 4.25.
CA, 343 r-a [941 r].
Bell actuation

Fig. 4.26.
CA, 343 r-a [941 r].
Float operated door
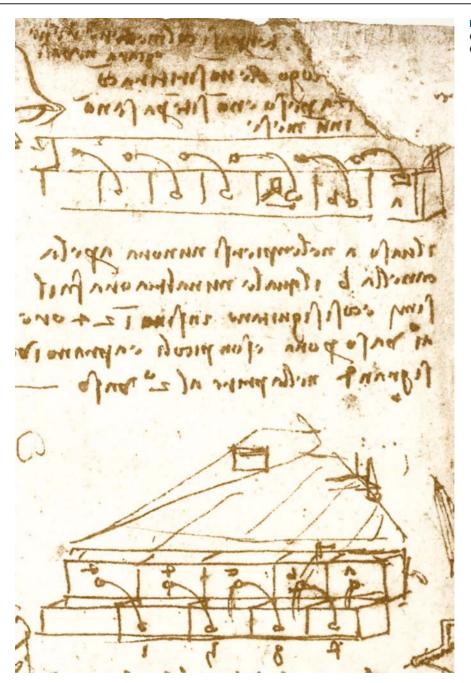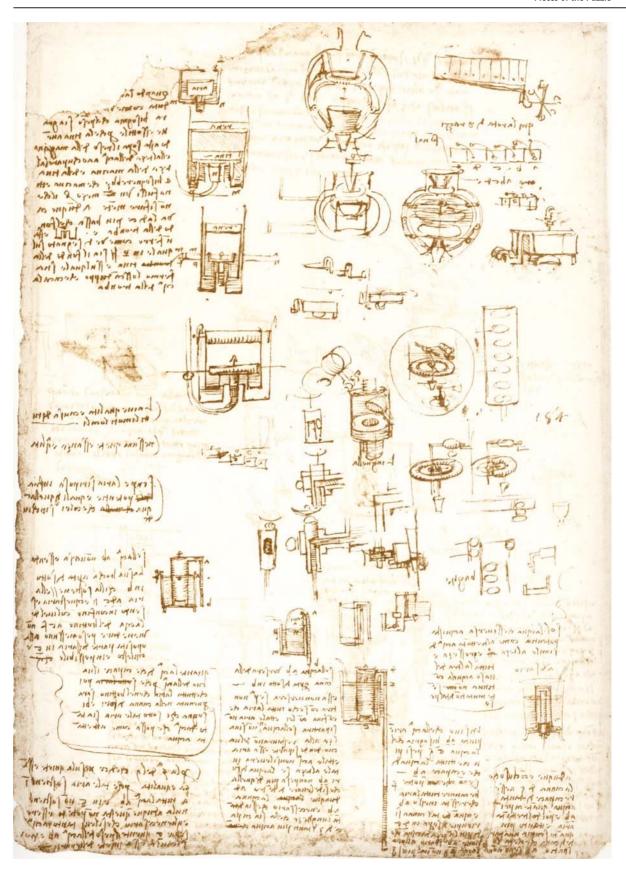
float that lifts open a door—a predecessor of the actuation/valve mechanisms. "Cicognola", a spiral siphon, is mentioned as in CA, f. 20 v-b [65 v].
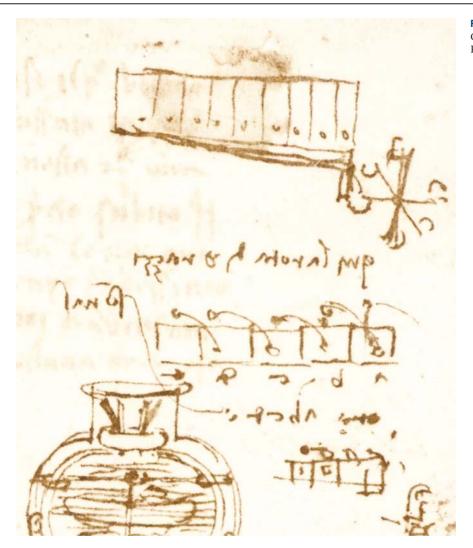
I looked at the operation information from a distance, unsure whether this was directly related to the Bell Ringer or to an earlier or later project. Various drawings of cascading reservoirs (Fig. 4.27), shown on the upper right of this sheet, are reminiscent of ancient Roman and Chinese clepsydra of the compensating tank type.[14]

Leonardo relates: "The *a* vase, while filling up in one hour, opens the little pipe *b,* which in another hour does the same; and they proceed this way for 24 hours, one

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[14] Joseph Needham, *Science and Civilisation in China*, vol. III, London, Cambridge Universtiy Press, 1959, pp. 315–329.

vase for each hour. And they are small and open the large vases while opening to the second vase". This was helpful because I could see the sequencing described and opening of the valves. And it indicated dumping the contents of the large vase, at the same time opening a passage to the second small vase.

Because the "baga" is mentioned, another interesting passage is:
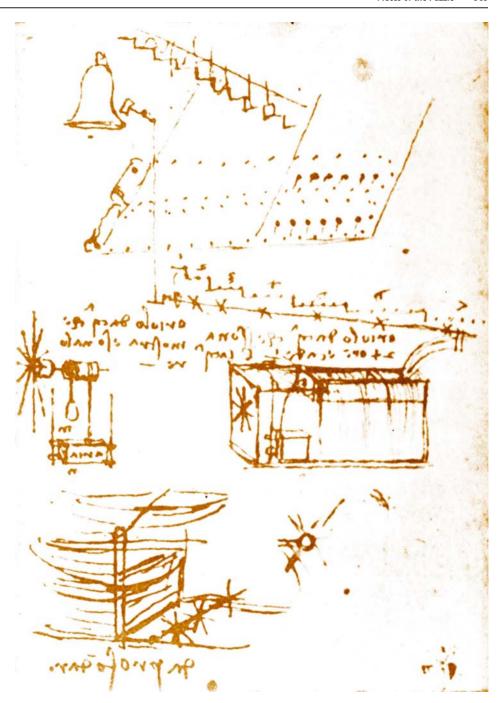
> With the help of the sixth proposition of the fourth book, the *a b*[15] vase pours its water in the *f* vase and lifts the "baga" that is inside it, with straight away unlocking of such sixth. And this, once unlocked, immediately comes to the surface and opens the *b* pipe with its "reverticulo"[16] and at the same time with the same speed it opens behind itself the vase that rings the hours.

Clearly, Leonardo is describing a two-part system: the vase with the "baga" and the vase that rings the hours, which is located behind the "baga" vase. The nomenclature and functionality was very similar for both the ringer and its predecessor. What was different obviously was the valve/actuator mechanisms.

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[15] Ms. "v": note 3 of the transcriber of the Leonardo's text (Augusto Marinoni) informs that Leonardo writes "v" when 'b' is obviously meant.
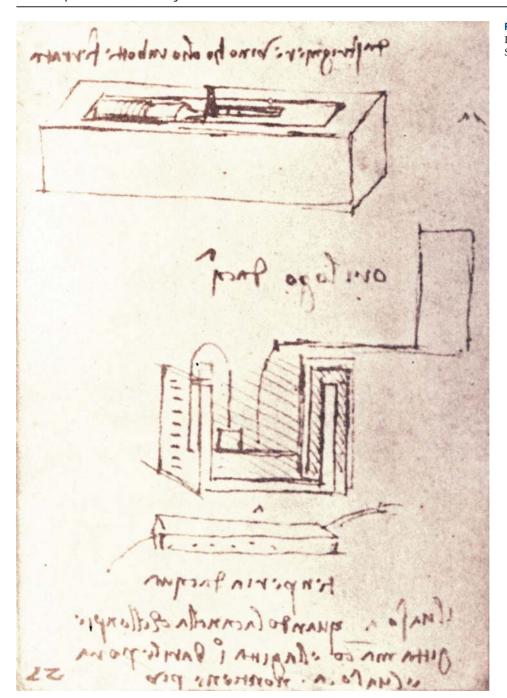
[16] Curved pole.

Fig. 4.30.
Paris MS L 23 v.
Studies for water clock

A paddle wheel with "razzi", or spokes, is shown as an actuator for the bell on a number of these sheets perhaps best represented by CA, 288 v-a [782 v] Fig. 4.28 and 4.29.

The small pocket notebook MS L also contains early conceptions of the water clock and it gives evidence that this project occupied Leonardo while even on the move. Folio 23 v of this notebook (Fig. 4.30) states: "Water clock that strikes twenty-four hours and drops one-half braccia of water". And: "Water clock that shows and strikes the hours". This is followed on f. 27 r in the same notebooks (Fig. 4.31): "Water clock. Governing ["temperia", meaning regulation of the "tempo", i.e. clock escapement] of
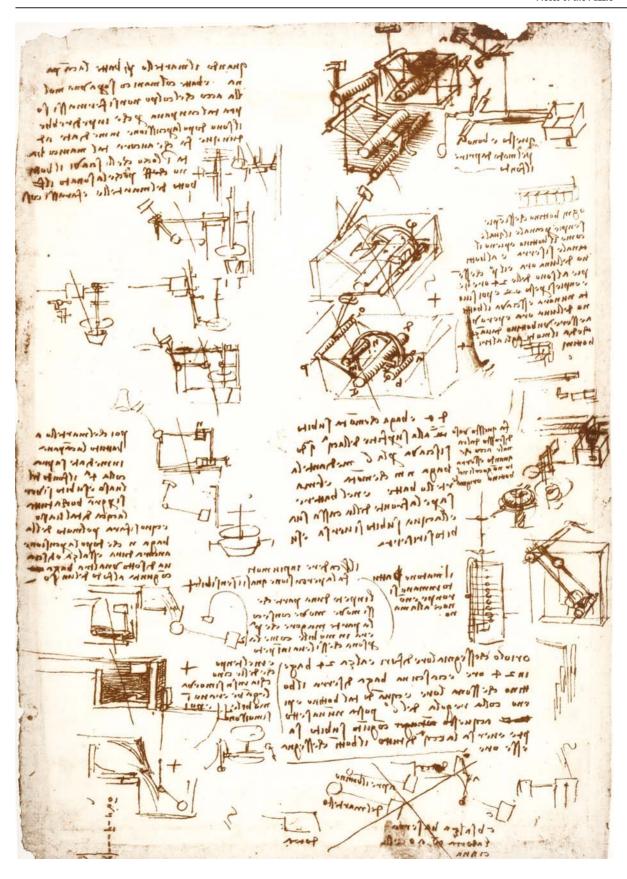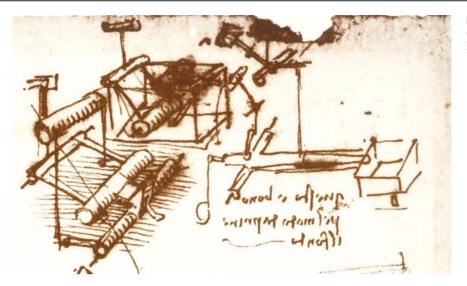
water". "When the faucet that fills vessel <u>a</u> spouts less, it spouts one barrel each hours, and vessel <u>a</u> will hold no more".

Finally, I needed to reconstruct the operation of the hammer hitting the bell. Folio 373 v-b [1042 r] of the Codex Atlanticus (Figs. 4.32 and 4.33) seems to be an early conceptualization of an alarm clock, not the Bell Ringer. The concepts for float actuated valves use leather bags and doors in place of actuator/valve assemblies used in the Bell Ringer. A canal is mentioned that was no doubt the source of water for the clock. The mention of leather bags ties this mechanism to CA, f. 343 v-a [943 r], CA, f. 343 r-a [941 r] and indirectly to CA, f. 288 r-a, v-a [782 r, 782 v] through the "Bringer".

The latter sheet, CA, f. 288 r-a [782 r] (Fig. 4.34), seems to be a preliminary version of CA, f. 343 v-a [943 r] since it has a similar operational description in its text and therefore may be connected to it and others in the series. The problem of uninterrupted time is dealt with in the first paragraph:

> If the hour 23 has rung, the first "bottino" is to be unlocked and to receive water for 2 hours and have the way out for two hours without ringing one, and then in the second hour it will ring the first hour. And this is done because, as soon as the 24 hour rings, the one hour begins and if in such time one had to start to fill the "bottino" that then has to pour water in order to make the one hour "bottino" strike the hour, and would be interrupted time.
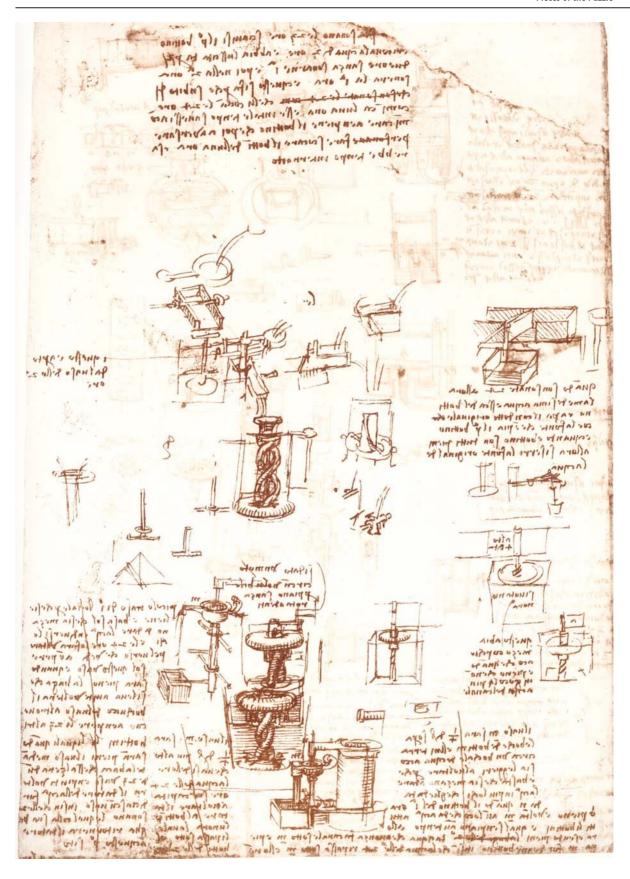
The second paragraph relates to the problem of when 24 (the end of the series) is reached:

> When the hour 24 has rung, then the same water is to evacuate the "bottino" and open the original pipe, that is the source which fills the first "bottino" and when the "bottini" are all full, then the original source of water is to be closed.

The last paragraphs describe the Bringer in more detail. Leonardo relates a plan to prevent interruption of time by starting the first hour after hour 23 has rung. To compensate for the extra hour, he gives the first container the capacity of 2 hours. He also discusses a rotating faucet, allowing it to contain "a jug of water" so that the friction is kept to a minimum. An entire automatic cycle is related.

On the top center of CA, f. 288 v-a [782 v] (Fig. 4.28) are two early versions of the Bell Ringer's bottino assembly in an earthenware vessel (Fig. 4.35). The tong-like linkage, *baga*, and conical float are nested inside. A second version (Fig. 4.36), below and to the right, is more like the final version from CA, f. 20 v-b [65 v] (Fig. 4.14). The valve stopper, which is also a float, is actuated by a "baga" float above it. Various floats and valve combinations are shown as well as a version of the actuator valve assembly in the center. On the right are cascading systems for a water clock that is not the Bell Ringer. This is evident because the upper right corner has a paddle wheel that uses the output of the cascading chambers. The rest of the pages consist of sectional views of valves, siphons, and float valve mechanisms. These sheets connect to the previous drawings in this series through the recto drawings of the "Bringer".

The problem of uninterrupted time is dealt with again in these pages. The complex "Bringer" appears again, with details on the rotating faucet, what it fills, and its interaction with the little barrels and finally the water of the 24 and its flow patterns. Maddeningly complex, the "Bringer" must be an early conception, for its construction, tuning and adjustment would have left little time for Leonardo to do anything else!
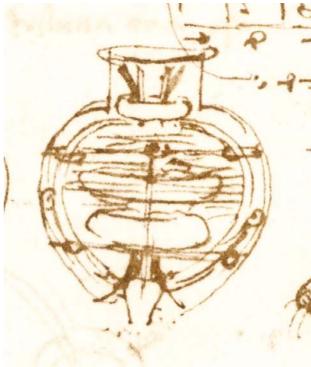
Fig. 4.35. CA, f. 288 v-a [782 v]. Earthenware bottino

Fig. 4.36. CA, f. 288 v-a [782 v]. Earthenware bottino

Reconstruction
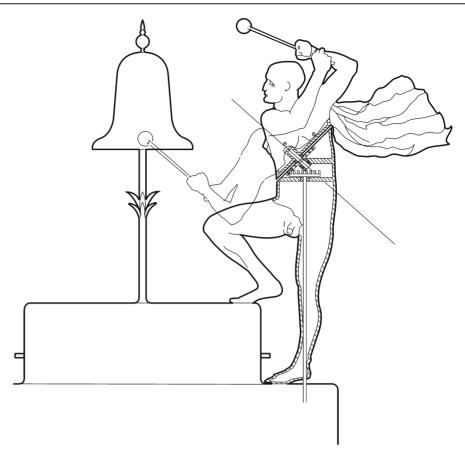
Even though the material seems scant, there is a great deal of information present. Beginning with the Windsor drawings, I could see that Leonardo was striving toward compactness and perhaps self-containment. As this was my most complete fragment of the overall system and the only one to depict the automaton, I gave it a high value. I started to see a separate earlier project—the alarm clock—and I used its operational information to glean clues for the more advanced system.

Using my "top-down approach", I set about to see how I would solve the problem, the first order of business being the automaton. Based on my technical knowledge I knew that Jacks had to be simple in order to operate through the high number of cycles demanded of them by a clock. Also, I knew that Leonardo, being Leonardo, might try to one-up the state-of-the-art by doing something more sophisticated.
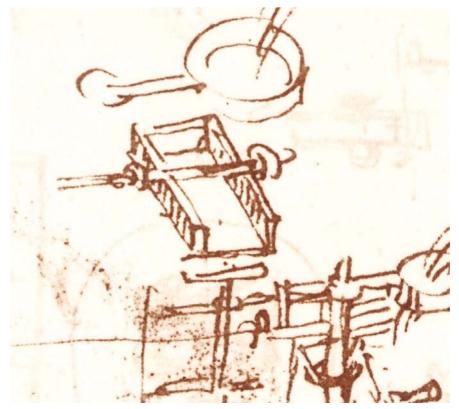
One possible reconstruction that would fit the surviving sketch is to have the upper body mounted on a skew-axis bearing (Fig. 4.37). The Jack could be powered by a rotating shaft passing through its left leg. The shaft could terminate in a bevel gear, which in turn drives another bevel gear connecting to the upper torso. Thus the ringer starts with the mallet above his head and swings down along the axis to strike the bell. This could be driven by a vessel that would receive and dump the water, causing the gear work to rotate the torso and then return to its original position. The more water, the more times the bell would ring.
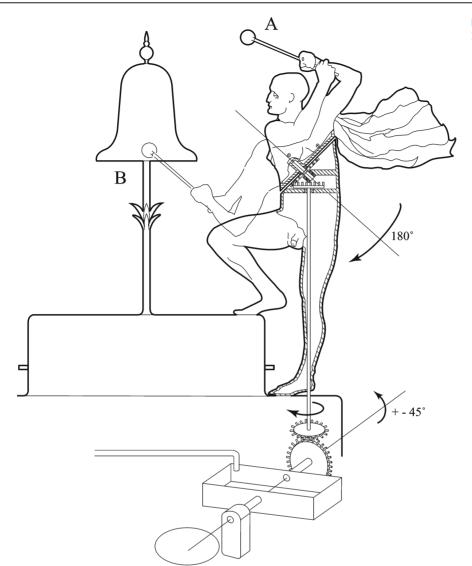
Perhaps a small paddle wheel was driven by the measured water being dumped from the containers, as shown in CA, f. 288 v-a [782 v] (Fig. 4.29): the more water, the more turns of the paddle wheel and thus the greater number of strikes by the Ringer. Or perhaps the wheel was driven by the bucket cable system shown in CA, f. 343 r-a [941 r] (Fig. 4.25). I suggest the simple tip bucket arrangement Leonardo shows in the upper left of CA, f. 288 r-a [782 r] (Fig. 4.38) that is found in Japanese gardens. The water fills the bucket until it becomes unbalanced, dumping its water and caus-

Fig. 4.37.
Upper body mounted on a skew
axis bearing

Fig. 4.38.
CA, f. 288 r-a [782 r].
Tip bucket detail

ing the ringer to strike once. This operates by gearing up to the Ringer, resetting with every tip of the bucket for another ring (Fig. 4.39).

Another reconstruction which may better fit the surviving illustrations would be to use hydraulic actuation of the Jack with a similar float-type arrangement in its torso that is fed by an "artery" of water through its leg. A cable system similar to that of the Knight is another possibility. However, cable systems (especially with materials of Leonardo's day) are notoriously unreliable and would tend to break down frequently, given the number of times a day they would be called upon to operate.
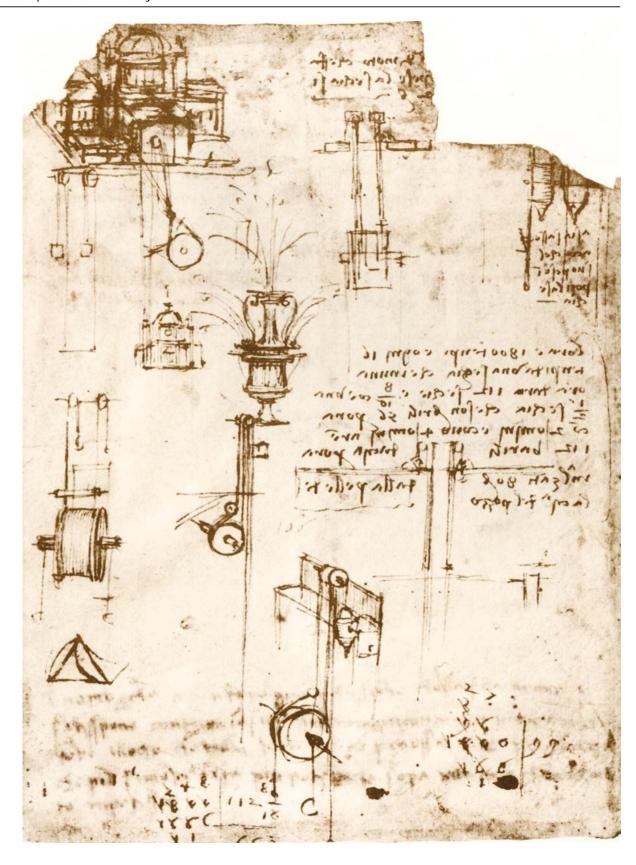
As I further investigated the Jack, to my mounting excitement I realized that it was spread throughout the Codex Atlanticus. Leonardo describes how the Jack-like man would deliver a blow in CA, f. 352 v-a [975 v] (Fig. 4.40):

Of the Use of Force By a Man Who Would Strike a Great Blow

When a man prepares to make a forceful motion, he bends and twists as much as he can in the direction contrary to that where he wishes the blow to fall, and thus he prepares a force as great as is possible for him, which he then brings together and, with a compound motion, launches upon the thing struck.

This is preceded by a fragmentary note on the mechanical principle inherent in the delivering of a blow, thus confirming the suspected reference to the Bell Ringer device:

> Why an impetus is not spent at once [but diminishes] gradually in some one direction? The impetus acquired in the line *a b c d* is spent in the line *d c* but not so completely but that some of its force remains in it and to this force is added the momentum in the line *d c* with the force of the motive power, and it must follow than the impetus multiplied by the blow is greater that the simple impetus produced by the momentum *d e*.

Significantly, on the opposite side of the sheet, CA, f. 352 r-b [975 r] (Fig. 4.41), next to architectural studies for a church, Leonardo shows a device to lift water from a well by means of counterweights and alternating buckets, along with notes on the amount of water lifted per hour. Carlo Pedretti relates these studies to the project for the church of St. Maria alla Fontana in Milan, which was founded by Leonardo's French patron Charles d' Amboise in 1507 on the site of a miraculous spring of water. In his catalog Carlo also notes, "a sketch of a vase, perhaps for a fountain."

An even more exiting discovery was in store as I traced the Bell Ringer through Leonardo's siphon studies. In Windsor 12641 (Fig. 4.42) we can see along side his studies of siphons are several studies for the Bell Ringer. They are depicted in two figures with hammer overhead, and one wound up like a baseball player (Fig. 4.43). Another figure is obscured from an ink smear, but may show a swing similar to that of a baseball player. Of particular interest is the trumpet blower, which may have been an alternative to the Jack ringing the bell (Fig. 4.44). It certainly would have had

Fig. 4.42. Windsor, 12641. Studies for bell ringer

fewer parts. Several siphons including a spiral siphon are shown. A simple hour glass water clock is shown at the top of the folio. Indeed, the siphons allowed me to trace the project directly to the Codex Hammer, which has siphons drawn on folios 3 v, 30 v and 34 v.

Little did Bill Gates know that when he purchased the Codex Hammer for over 30 million dollars, that he was also purchasing a document linked to the birth of digital computing concepts!

A more complex problem is the reconstruction of the hydraulic controller that not only caused the bell to ring on the hour but also to ring the number of hours. The 24 containers are clearly shown in Fig. 4.9, but lack any mechanism that would indicate interconnection, valves, or a sequence generating mechanism. So my first thought was to use the text as a specification and build a mental image of 24 simple containers to see if I could make them work as indicated in Leonardo's notes. I thought it

would be something like the cascading systems that have been used in Roman times,[17] as shown in CA, f. 288 v-a [782 v] (Fig. 4.29) and CA f. 343 r-a [941 r] (Fig. 4.27). This broke down because the timing of the hour and the ringing of the hours are two separate operations. So I looked to what I felt were the most closely related drawings for inspiration. Looking at CA, f. 20 v-b [65 v] (Fig. 4.14), I could see the mysterious actuator/valve, but most importantly, another container lightly drawn above it. This would simply contain the unique quantity of water required to ring its hour. Looking at CA, f. 362 v-a [1011 r] (Fig. 4.21), I saw again the lightly drawn containers above the valves. Leonardo did not bother to detail them as they are simply containers. This would also explain why you see only circles within the main housing in the Windsor drawings no. 12688 and 12716 (Fig. 4.9)—there is nothing more to see.

The next step was to understand how the actuator/valve mechanism fit into the overall scheme of things—it was a key component, and perhaps it would teach me how the containers were interconnected. As described above, I could see clearly how the mechanism in CA, f. 20 v-b [65 v] (Fig. 4.14) functioned. I understood that when water filled the container the pair of floats would work together in perfect harmony. Leonardo's trigger concept—connecting the upper float by a scissor-like linkage inside the hollow helix to the lower float—was a model of economy. Once the container filled, the "handles" of the scissors would be squeezed by the ascent of the upper float. This would cause the restraining "blades" to move inward to release the bottom float, allowing it to ascend, and thereby rotating the helix and turning the valve (see *Operation* and *Building Leonardo's Bottino* below for more information).
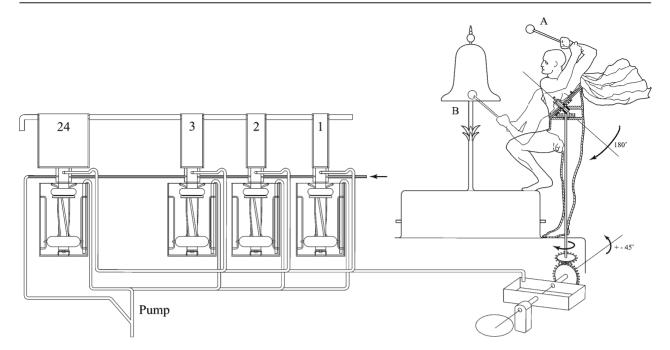
I then connected these in series as indicated in CA, f. 362 v-a [1011 r] (Fig. 4.20) and the top of CA, f. 343 v-a [943 r] (Fig. 4.22) and could see them keeping time in one direction. Was the dreaded Bringer needed to reset this system? The prospect of costs (to say nothing of the mental anguish of reconstructing the Bringer) was so dreadful that it provided an excellent incentive to find an alternative—as it may have for Leonardo as well. Also, why did it not show up in Windsor drawing RL 12688, which clearly shows a top view? Surly he would have detailed the rotating faucet mechanism. Also, I figured that a dump valve must be used at the bottom of the lower containers, but none was shown in key drawings. So again, how are they emptied and what was the spiral siphon? Could this be a clue?

Searching on the Internet to learn more about siphons, I saw a remark about how more reliable they are than other means of draining tanks. Well, reliability would be critical in this system. Also, the translator's preliminary word for *cicognola* is "stork", not "spiral siphon". The image of a stork made me think of a more conventional siphon, which is a long straight tube bent in half, and then it hit me: once the siphons got going, they would operate on their own—they would not interrupt the sequence of time and could be used to reset the entire system. I could use the water flowing from container 24 to pass a port connected to the siphon line. The resulting pressure drop would start the siphons. Although the idea has been attributed to Johann Bernoulli [1667–1748] I assume that Leonardo and even the ancient Romans knew the basic principle. Leonardo would have been well acquainted with siphons and their theory of operation from the introduction to Hero's *Pneumatica*,[18] which even included an early example of the scientific method. Leonardo was also seeking Archimedes treatise and must have located it as his notebooks illustrate his work on siphons.

How all this would come to be assembled was another issue. Thanks to the siphons, no plumbing would be required at the bottom of the containers. They could just sit there in the bottom of the fountain. Piping of the siphons, ringer line and siphon starting line could be routed down between the cylinders and connected together in the lower base, either through a common manifold or through a circular

[17] Joseph Needham, op. cit. (as in note 14 above) plates XLIV and XLV.
[18] J. G. Landels, *Engineering in the Ancient World*, Berkeley, University of California Press, 1978. There is an excellent description of Archimedean siphons on pp. 192–194.

pipe tapped with little "T"-blocks. I assumed the plumbing would be lead tubing and would be soldered or perhaps glued in place with asphalt. The upper containers would likely be removable to enable access to the plumbing below. Although ceramics are mentioned for constructing some elements of the system, I think that the upper and lower containers were most likely soldered brass or bronze because they are easy to work with, rugged and corrosion resistant.

All this occurred to me by flipping through my pile of Leonardo drawings over and over again, sketching version after version, building my mental image of how it functions. Locking down the understanding of a subsystem here, another there; loading dozens, maybe hundreds, of images into my subconscious; flipping faster and faster, I watched until, as in an antique peephole kinetoscope, I saw the individual frames begin to flicker and start to move. An image appeared—a beautiful image—of what had been lost and what was again, at last, brought forth to the light of day. Finally, I had it—after nine months of research, thought, and above all sketching, I had a solution (Fig. 4.45).

This key discovery of how the valve/actuator functioned not only solved the operation of this component, but also showed me that the valve/actuator was a sequencer of the hours and would be identical for all 24 hours. Now I understood what Leonardo meant when he wrote in Windsor 12688 (Fig. 4.9) "bottino all alike." This would have been an important consideration, not only for reliability but also for cost effectiveness—a small assembly line would have been set up to fabricate the actuator/valve assemblies.

Operation

From the diverse descriptions of at least two different designs, I arrived at a general theory of operation (Fig. 4.46). In all versions, Leonardo indicates that this is at minimum a two-part, or "binary" system using 24 containers—the "container of the hours"—that is, the unique quantity of water that will reproduce the required number of bell strikes. Below are the "bottini", or "little barrels" containing float mechanisms that actuate overhead valves. The little barrels provide sequencing and control the flow of water from the "original source". Each barrel fills in one hour (in one version), then releases the "container of the hours", each one a quantity of water that will generate the proper number of bell strikes. All container of the hours flow out through a common line. The top of the "container of the hours" may be seen in the

Fig. 4.46. Bell ringer computer
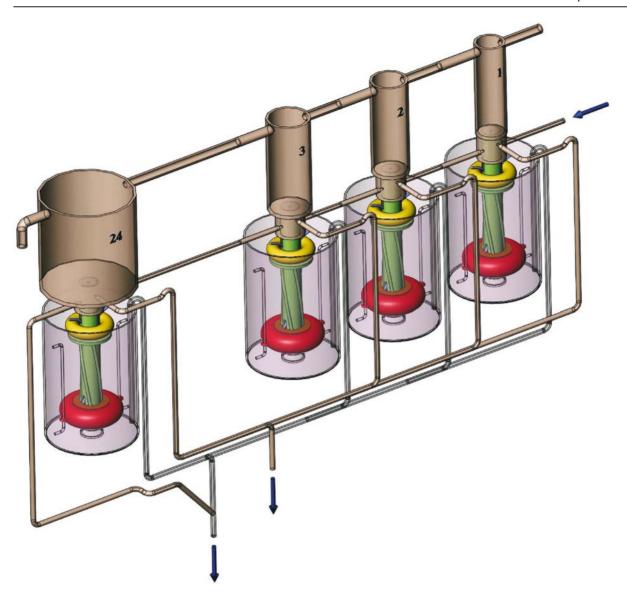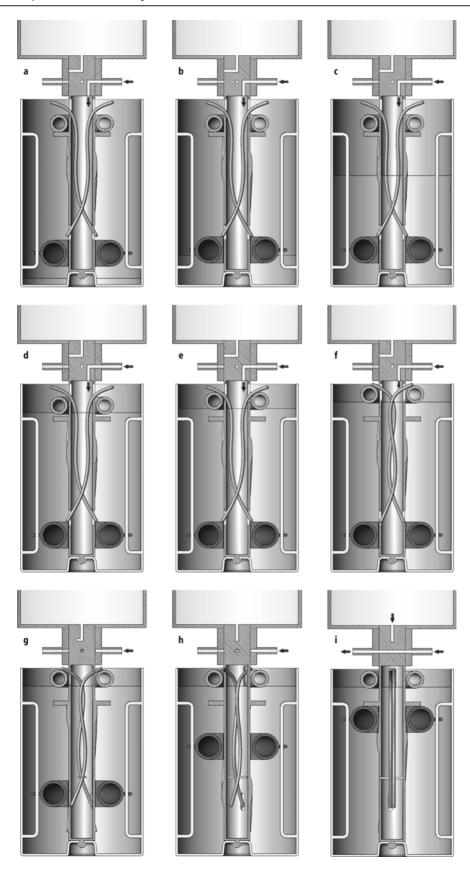
Bell Ringer illustration on Windsor, RL 12688 (Fig. 4.11), with the "little barrels" located below them.

In brief, water is admitted from the canal. It is directed by valve number 1 to fill the little barrel. When the little barrel fills, the upper float rises and unlocks the lower float via its linkage (Fig. 4.47). This float rises rapidly, rotating the helix and thus turning the upper valve stem. The valve releases the water in the upper container to actuate the Ringer, simultaneously opening a port to allow water to flow to the next unit—repeating the cycle.

When the twenty-fourth hour is reached and the upper container is dumped, the water flows to the common dump line, creating a pressure drop that starts all the siphons, which are connected by a common line. When all the lower containers are drained, the floats return to their original positions, resetting the system. The container of the hours could all be refilled while hour 1 is filling (it must fill in that time) via its valve by adding another port to admit water to the upper container. Another method would be let the additional port open into the main fountain housing, flooding the entire fountain with the water spilling over and into the containers. This would agree nicely with the principal Windsor drawings RL 12688 and RL 12716 (Fig. 4.9).
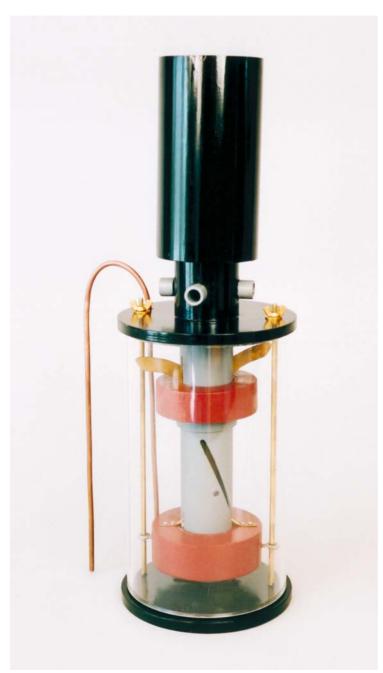
Building Leonardo's Bottino

To prove that my reconstruction of Leonardo's Bottino was valid I set myself the task of building a single working Bottino. The helix and valve stem seemed the most difficult to build so I started there and let the components define the rest of the system.

Initially my Bottino container was an antique battery jar but as the reconstruction evolved and looked better and better I splurged the big money on a foot of Plexiglas tubing. Also, in my only successful departure from Leonardo's original design, I screwed the guide rods directly into the wooden end cap tying them to the top cap with wing nuts. This, with the help of some very modern O-rings, would make a very rugged and watertight Bottino.

Fig. 4.48. Working model of bottino
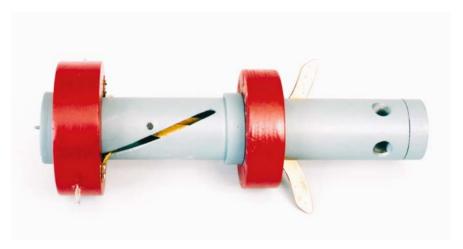
I carefully chose my materials from my stockpile of bits and pieces I keep stored under my work benches. I made the linkages out of brass and tried to do away with the upper wings of surplus material Leonardo had designed. To my surprise I quickly realized that they were for creating a bias to force the lower baga restraining tabs outward. So much for redesigning Leonardo! Great care was needed in choosing the material for the lower baga as they had to rise and descend with enough forces to set and reset the upper valve. Day by day and hour by hour the bits of wood, plastic and metal began to resemble Leonardo's creation. Once the components were assembled I started to fill and putty in all the voids and imperfections, sanding and re-sanding the filler until I had a smooth-as-silk surface. Layer after layer of primer was sprayed and sanded until at last I could apply the final coat of paint. I chose a barn-like red, oil-based paint for the baga, as it recalled the paint I saw in the Life of Leonardo episode where the sphere was being fabricated to cap off the Florence Cathedral's dome. I painted this and the other parts by hand, not by spraying, to give the model a more antique look (Figs. 4.48–4.50).

A few feet of copper tubing from my local hardware store and a bending guide and presto! I had a siphon! The upper container of the hours I made out of a simple piece of tubing. In an actual system the container of the hours would be larger than the Bottino. As discussed above the scissor linkage of the Bottino and the scissor linkage of the programmable automaton of Chapter II were very similar (Fig. 4.51). Apparently, Leonardo would reuse certain design elements in his robots. At last I had my finished machine. But … would it work?

Fig. 4.49.
Disassembled bottino
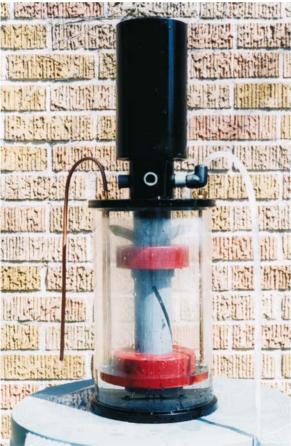
Fig. 4.50.
Floats, helix, and valve stem

To test my Bottino I set it on a small stand outdoors and began to fill it with my garden hose (Fig. 4.52). Slowly, the container started to fill with the lower float standing still. Finally, the upper float was also covered with water and started to rise. Would it work? Would the upper float release the Bottino? Suddenly, the upper float jerked up (Fig. 4.53) and the lower baga rose, turning the helix and spinning the brass linkage counterweight wings. The valve now rotated, water gushed forth from the upper container, and the supply water was free to pour out of the left port (Fig. 4.54). I could only think of the line from Moby Dick when, upon sighting the great white whale, the lookout cries, "She breaches!" To reverse the action I sucked on the siphon to prime it and watched with satisfaction as the upper baga dropped with the water level to its stop, resetting the linkage. Then the lower baga began its longer descent

Fig. 4.51.
Bottino trigger linkage (*left*)
programmable automaton
linkage (*right*)

Fig. 4.52. Lower container filling
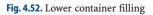
Fig. 4.53. Lower float released – helix turning

finally pushing down and in the linkage tabs. Once past them they snapped out relocking the baga for its next cycle. I had seen with my own eyes the first digital logic element.

In this section we have looked at the ancient forebears of Leonardo's Bell Ringer as well as the Ringer itself. Utilizing Leonardo's legacy of fragments, we grouped them into two projects. Applying my "bottom-up approach" and creative engineering for the "top-down approach", we reconstituted the Bell Ringer for the first time in centuries. Even in Leonardo's day, a water clock was an anachronism. But no doubt pressed by a demanding patron, Leonardo rose to the challenge and produced a fascinating, modular, compact, and reliable clock that anticipates modern, computer-like functionality.

The key difference between Leonardo's clock and those of his predecessors is the modern conception of modularity and compactness. The Chinese water clock could tell time, too, and likely rang the hour, but it required a building to house it. Its predecessor, the Tower of Winds, also could tell time, but lacked the chiming of the hours function. Always sought after, but seldom achieved, were ease of maintenance, reliability, and manageable cost. Like his followers centuries later, Leonardo realized that in a digital system individual components do not have to be made precisely if they are representing only two states i.e. 0 or 1. Leonardo's accomplishment marks the first occurrence of a sequence controller in the modern sense of a simple, dedicated computer that performs its job for telling time and entertaining those who saw it.

Fig. 4.54. Valve actuated: upper container and line water streaming forth
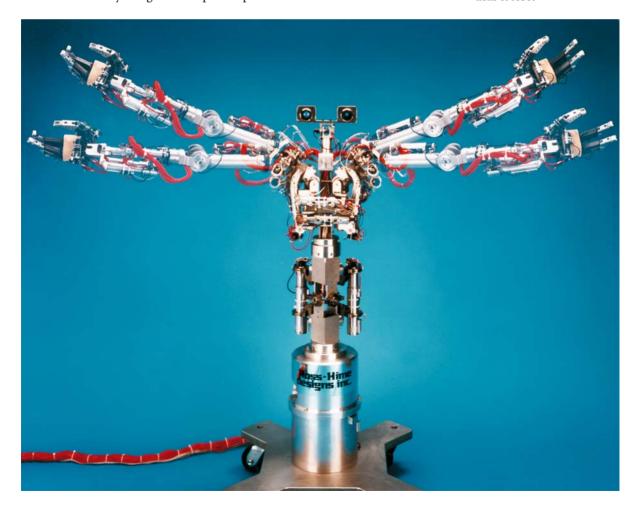
Epilogue
Leonardo's Legacy and Impact on Modern Technology

Leonardo's life-long career as a roboticist would bridge the fifteenth and sixteenth centuries. Leonardo's relationship with his teacher Verrocchio was doubtless the foundation of his work with robots. Perhaps Leonardo even sought to outperform his mentor, striving for even greater technological glory. Not surprisingly, it would take exactly that type of teacher/student relationship in our modern time to reassemble Leonardo's lost robots. Obviously in love with the technological challenges of mechanisms, Leonardo at an early age shows an astonishing grasp of how to integrate multiple subsystems to accomplish his goal of a self-propelled, compact programmable automaton, perhaps located in the base of a mechanical lion, which would follow a prescribed pattern. In mid-life, he would create an animatronic knight, also for entertainment purposes. Towards the end of his life, he would invent a hydraulic clock in homage to the clepsydras of the ancients but with very modern concepts of components and packaging.

Fig. 5.1.
Spenser lathe

In the Programmable Automaton, with its beautiful nested subsystems and dual spring power supply, we see the foundation of the first programmable machine tools, to say nothing of the first Autonomous Ground Vehicle (AGV) that would become common on the twentieth century factory floor for moving manufactured components and subassemblies. Flexible programming is provided by removable cams for steering and actuating additional subsystems—dare I say subroutines? The spring return cam followers actuate stop and start functions and steering. This is a clear anticipation of the nineteenth-century cam-operated machine tools. In 1893, Christopher M. Spenser filed his patent on a "Fixed Head Type of Automatic Lathe for Making Metal Screws Automatically." Controlled by curved plates on rotating drums, it was very similar to Leonardo's some four hundred years earlier. Leonardo's machine is a direct anticipation of the technology that fueled the industrial revolution, with the same use of rotating cams to control machining operation (Fig. 5.1). Spenser's would be the prototype for countless cam-controlled automatic machine tools. From these numerically controlled machine tools would evolve machines controlled by punched tape and eventually modern software.

In the Robot Knight, with its remote control potential and anthropomorphic physique, we see the birth of animatronics, or entertainment robots. No doubt designed for a fifteenth-century amusement park, it must have shocked and amazed visitors who came upon the mechanical apparition standing up and outstretching its arms. That the unique differential cable drive system for the arms would be reborn 500 years later as an exercise machine shows Leonardo's wonderful cleverness in designing multi-functionality using a few simple components. Animatronics would in the twen-
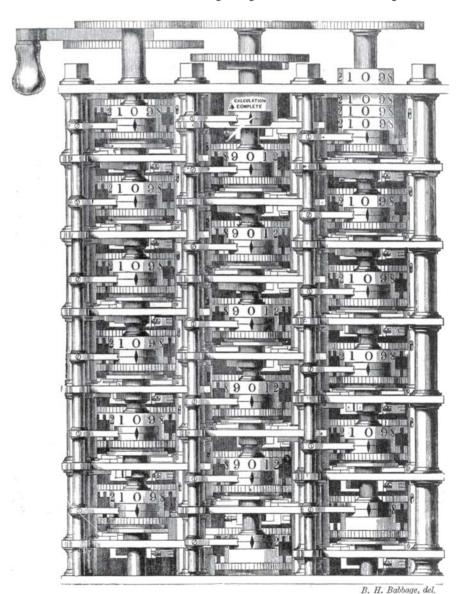
Fig. 5.2. Robotic surrogate proportions of robot
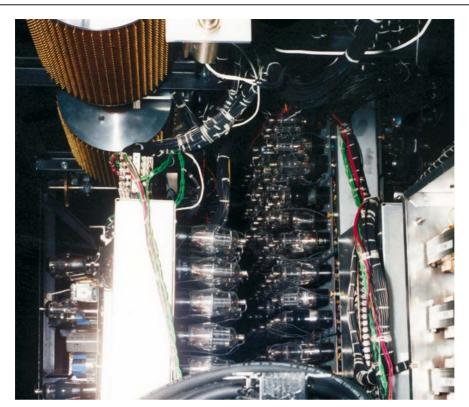
tieth century be made famous by Disney and developed further by myself for NASA (Fig. 5.2). These twentieth-century inventions would continue to fulfill the need for entertainment, at the same time leading to modern anthropomorphic robots for space and hazardous duties. They show an amazing similarity to their 1950s science fiction counterparts made famous in countless B-grade movies. Perhaps someday they will become our domestic servants.
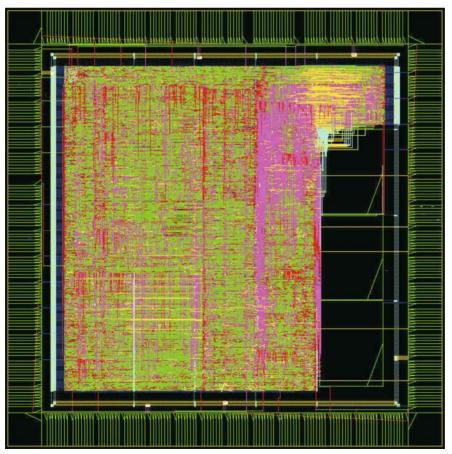
Perhaps the most futuristic of all of Leonardo's robots is the controller for the Bell Ringer. Here we see the advent of digital logic elements and the harbingers of electronic circuitry. Leonardo invented what in the twentieth century would be called "Fluidics," utilizing pressurized fluids for control and actuation. This technology would be made obsolete with improvements in computers, controllers, and electric actuators but their function would remain the same. Logic elements, those ubiquitous, highly repetitive devices, would for the first time be produced by Leonardo's tightly packed "bottini." In the nineteenth century, rows and columns of gear wheels (Fig. 5.3), then twentieth-century vacuum tubes (Fig. 5.4), and most recently, transistors, would become the modern art of our technological age. We see Leonardo striving for "com-

Fig. 5.3.
Babbage difference engine no. 1

B. H. Babbage, del.

Fig. 5.4.
Attanaoff Berry computer

Fig. 5.5.
Micro-chip

pactness" of his elements, just as modern designers continue to pack more transistors into every nanometer of microchip. Leonardo would also pack his "bottini" elements in as tight a circular cluster as possible, not unlike silicon wafer manufacturers that strive to squeeze the maximum number of transistors into every chip (Fig. 5.5).

The technology would go full circle with modern micro-processor based controllers driving modern day fountains with articulated jets synchronized with popular music by an underground vault full of electronics, computers, and software. Just as with Leonardo's Bell Ringer, every hour on the hour, the fountain performs its feat to the entertainment and delight of modern visitors who applaud at the end of each cycle. These circles of water jets could very well be the same number as in Leonardo's fountain (Fig. 5.6). This modern day fountain recalls Leonardo's own words, "let a harmony be made with different falls of water, as you saw at the fountain of Rimini, as you saw it on August 8, 1502." The circle is complete—Leonardo's vision again reaches beyond the horizon to guide us into the future.

Fig. 5.6.
Ross-Hime Designs, Inc.
Omni-Wrist articulated fountain,
Los Angeles, California

Appendix 1
Leonardo on the Bell Ringer Water Clock

All the Leonardo texts on sheets of the Codex Atlanticus pertaining to his project for a Bell Ringer Water Clock are here translated into English for the first time. The translations by Translatia are from Italy's National Edition of Leonardo da Vinci, *Il Codice Atlantico della Biblioteca Ambrosiana di Milano*. Trascrizione diplomatica e critica di Augusto Marinoni, Firenze, Giunti Barbèra, 1975–1980, 12 volumes of text and 12 volumes of facsimiles. Texts marked by an asterisk are those that Leonardo himself crossed through as evidence of having elaborated or transcribed them somewhere else, normally in manuscripts now lost. The presentation in English follows exactly the Italian by Marinoni, including his descriptions of each sheet as well as his notes, to which the translator has added his own indicating them as such. Occasional bibliographical references given by Marinoni in abbreviated form in his comments are only two, as follows:

Beck = Theodor Beck (1906) Leonardo da Vinci (1452–1519). Vierte Abhandlung: Codice Atlantico. *Zeitschrift des Vereines deutscher Ingenieure*, L, pp 524–531, 562–569, 645–651, 777–784

Clark-Pedretti = Clark, Kenneth and Pedretti, Carlo (1968/1969) The drawings of Leonardo da Vinci in the collection of Her Majesty the queen at Windsor Castle, Second edition. Phaidon, London New York, 3 volumes

Folio 782

Recto

Formally 288 r-a; 300×212 mm; very transparent paper, narrow columns at intervals of 22 mm; central watermark ('snake'); to be compared with ff. 65, 941 (whose ancient numbering is contiguous to the one of the current sheet) and 1042 due to the identity of paper and topic. This one consists of the plan of a water clock with alarm (see Beck, pp. 651, 530). The tear of the upper margin has damaged the text.

- On top

  … If the hour 23 has rung, the first "bottino"[1] is to be unlocked and to receive water for 2 hours and have the way out for two hours without ringing one, and then in the second hour it will ring the first hour. And this is done because, as soon as the 24 hour strikes, the one hour begins and if in such time one had to start to fill the "bottino" that then has to pour water in order to make the one hour "bottino" strike the hour, and would be interrupted time.

- Towards the center; The probable overall view of the machine, followed by

  This is open by the vase of the 24 hour

---

[1] "Bottino" = little barrel. However some introductory remarks in the folio 941 point out that "bottini" are actually cylindrical containers used to contain water. I therefore decided to leave the original lexeme throughout the text. [translator's note].

- On the right, "bottini" system

When the hour 24 has strikes, then the same water is to evacuate the "bottino" and open the original pipe, that is the source which fills the first "bottino" and when the "bottini" are all full, then the original source of water is to be closed.

- Detail of the Instrument

4 finger[2] high. It empties in one hour.

- Similar illustration with: a

This is to have a half lid so that when it is full, no water of the channel will drip on it.

- At the bottom, Instrument with: n – m

* The vase *m* will be ¼ braccio[3] above the openings of the "bottini" and it will contain about a jug of water, so that it is light when it turns, since it is sufficient that it is half way full for it to provide water to several places; it is given to it by *n*; when the one hour "bottino" is full, *m* is turned to a place that provides water to all the "bottini", which are filled at the same time; then, being full, the water that remains forms a channel under *m* and folds *m* outside each "bottino", until the water of the 24 flows again under *m* and gives it back to the vase of the first hour as before. This way it keeps going.

- Illustration above the preceding one

* A round motion on a flat surface with no wheels or cogs is to be given[4]

- Illustration with: m[5]

* The vase *m* will be ¼ braccio higher than the vases of the hours.
* The water of the hour 24, if[6] it happens to turn the water giver to one hour "bottino", which[7] flows underneath the "bottino" of the hour 2, it turns the giver away from every "bottino", all …
* Little vase with the capacity of one jug. In order for it to be light, it is enough that it is half full to provide water to different places, and the 24 hours will make it turn in the way you see it filling just this vase, and when it is full, the float that comes up like a screw, will turn the lip of the vase elsewhere, namely to fill the other 23 "bottini", which, once they are full, the vase, thanks to the "baga" that will raise out of one of the 23 filled "bottini", will turn the giver of the water out of each vase, until the 24 rings, and the giver with its "baga" will come back to this first site.

Verso

Formerly 288 v-a; ancient numbering 184 (the f. 941 has the number 183 on it). One of the illustrations in the upper right corner is more thoroughly developed and ex-

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[2] Dita = fingers [translator's note].
[3] A unit of measurement. Braccio = arm [translator's note].
[4] Round motion = "Circumvolubile per piano".
[5] The two illustrations marked with the letter *m* effectively represent the same machinery and the relative captions say the same thing with minor variations.
[6] Hard to read stained word, as others are in this paragraph.
[7] Referred to the water [translator's note].

plained in the f. 941 as a complex of "bottini" that measure and signal the hours of the day. Various other drawings are reminiscent of those in the front, but most of the space is dedicated to different shapes of small tubs that fill and empty out, mostly represented in the longitudinal section.

- Right column, following the first illustration

  Here the wheel of 8 spokes.

- Five "bottini" with: e d c b a

  a b c d e are vases

- Under the illustration in the center

  Little tongue

- Little illustration with five little circles

  Floats

- Double cylinder inside a vase, with: Adversary

  Only the water that is poured, gains power like an equal amount of water of similar height and thickness, and all the other in the vase continuous to that does not feel any variation of such weight.

- Illustration of a cylinder inside a vase and pipe allowing the water to flow out, with: a d – b e – c – f – g

  Until the water has filled *a b*, it is necessary that the water *e g* be heavier than the water of capacity *a b* – if this weren't the case it could not remove all the air remaining in *a b*; and when this pipe fills above in *d* and for a length which is more than the space available in *a b*, then the water *f g* does not count any more.[8] It is therefore concluded that the pipe *d g* must be able to contain as much water as the capacity of *a b*, and later the same amount of air, and even more than a part of the pipe is filled that is from the space *a b;* otherwise, it does not hold.

- Similar illustration, with: a – aria – p n – m – b

  If the *a b* water will pour from the open pipe to *b* underneath. —It will not pour, if it first hasn't dragged along all the air that borders with it; and such air won't leave, if the water *n* does not raise high enough to the restoration of the vacuum, from where such air will leave, and such water won't raise to such an height, if the water outside *a b* won't be heavier than that which has to be leave from inside. Therefore the pipe *a b* has to be of such length that its capacity is such that it can contain 3 times more water than the capacity of the air vacuum[9], because, after the water that is in the "bottino" will have moved in the pipe outside, it is necessary that under such air there is an amount of water, whose power equals an equivalent amount of water.

---

[8] Following "più" a vertical line (read "f" by P.) is used in the MS to separate from this text the "g" that follows which belongs to the illustration.
[9] Ms. "acqua" (water).

Left hand column, from the top

- Three illustrations of small tubs, with: aria – m n; rena – tina – n(m) – p m; rena – m m a – f p n

When the … [duta] like … [ra], it is necessary that the weight be heavy and thin, because since the vat has to stay on top of the weight of the millstone and the height of the water has to occupy the height of the millstone and of the vat, it would be necessary that vat and millstone were a half braccio, and that would be nothing to be done. Finally empty the lowest root that the bottom of the "tromba"[10] (*small illustration*) make an iron, as you see marked, on which in p[11] be the bottom of the vat and on which the scanduppo[12] stay steady, which forces the water into the tromba. The inequality is the cause of all the local motion. No quiet is without equality. The air always rests among equal powers of that water that is enclosed with it.

- Cylinder inside a vase, waste pipe with: d – a – f c a – b

If the *a b* water is not pouring, being its opening open below in *b*, what is it that sustains it? It is the air *a d c*, and such air, bordering with the water level of the "bottino" *a c f*, does not provide any weight at the opposite side of the air in *c*. And this is impossible for the fifth proposition of the ninth book, which says: "no quiet is without equality", because such air sustains in *a* all the water *a b*, and in *c* it doesn't sustain anything. Therefore, being this impossible, it is necessary that there raises above *c* as much water as the weight of the water *a b*, and then such quiet of the parts is obtained.

Folio 941

Recto

Formerly 343 r-a; ancient numbering 185; 297×199 mm; transparent paper, very weak little columns, 22 mm from one another; tear in the margins with mutilation of texts and drawings; sheet to be considered together with ff. 65, 782, 1042. Notes and drawings are about the construction of a water clock with alarm (see Beck pp. 650–651). The right column studies mainly the system of drawers or "bottini", the left one the devices used for their emptying and the alarm. Arithmetical operations: the squares of 15, 16, 17, 18 corresponding to 225, 256, 289, 324.

- Right column

… Regulate "temperare"[13] by putting sand or gravel in the vases.[14]
… clock[15] which does not go back against the weight and does not need to be adjusted that once a month.

---

[10] tromba = trumpet [translator's note].

[11] Ms. "o" with the first part of a little descending sign interrupted by the underlining of the letter. On the other side of the illustration the letter "p" is present, but "o" is not.

[12] Scanduppo = stantuffo [= piston, translator's note] appears several time in da Vinci's writings. According to Tommaseo the term is found for the first time in the "Pirotecnia" by V. Biringuccio (Venezia 1540) in the form "standuffo", and later in Galileo as "stantuffo". It is likely to have originated from German "Stampfe" (merged with "tuffo") whose affricate "pf" would have been rendered by Leonardo as "pp" and by the others as "ff". As to "c" in lieu of "t" one might hypothesize a dissimilation.

[13] "Temperare" could either mean "mix in the right proportions" or "to build, forge". This latter usage of the word is attested in Dante's writings (XIVth Century Italian) [translator's note].

[14] See the vases loaded with sand in the f. 782 v [288 v-a].

[15] Ms.: […] og<i>o", i.e. "orologio" (clock). We don't know whether in the missing part of the paper there existed a drawing as well or just words. In the latter case between "con" and "tra peso", between "se non" and "n un mese" there might have been letters of syllables now lost.

- Row of "bottini", with: b a

The *a* vase, while filling up in one hour, opens the little pipe *b,* which in another hour does the same; and they proceed this way for 24 hours, one vase for each hour. And they are small and open the large vases while opening to the second vase.

- Similar illustration, with: e d c b a – i h g f

With the help of the sixth proposition of the fourth book the *a b* vase[16] pours its water in the *f* vase and lifts the "baga" that is inside it, with straight away unlocking of such sixth. And this, once unlocked, immediately comes to the surface and opens the *b* pipe with its "reverticulo"[17] and at the same time with the same speed it opens behind itself the vase that rings the hours.

And in this case 3 vases are to be used, the first of which is *a*, and this is poured precisely in one hour, and all the others that are on the same line will do the same. The second vases below, while filling up in the same hour in which those above them pour the water into them, and as the vase below fills up, it raises and unlocks the baga of the second vase *b* in the way described in the sixth. And this way the *b* vase empties and the *g* vase fills up in another second hour, and the vase behind rings its hours. In the process of opening the pipe for *b*, the vase of the hours gets opened as well and this way, when the *g* vase empties the way of the fourth "a siphon"[18], the vases close again, and after 24 hours have rung, in the hour that follows all the vases that strike[19] the hours and those that ring the hours have to be filled. But the vases below only happen to fill hour by hour, as stated.

- Illustration with smeared ink: wheel, shafts and rotating cylinders, with: (4) 3 2 4 4 – 8 16

All the water coming out of each that strikes the hour vase, flows through one and the same channel to one and the same wheel with 8 "spokes",[20] and such wheel immediately fills one of the boxes, which move down sustained by one time[21] so that they can wait to be full and their moving down does not occur forcefully.

Right margin

- Little illustration, with: og

- Overall view of the bottini

All the bottini that ring the hour have to be filled between the 24 and the one hour; and the first does not ring but for an hour to pour his[22] water and then it unlocks the one hour bottino.

---

[16] Ms. "v".

[17] Curved pole.

[18] "Cicognola" means spiral siphon. In current Italian; "cicogna" = stork [translator's note].

[19] Ms. "sconcano", but see the f. 782 r [288 r-a]. where the verb "scoccare" is repeated: here it looks like "scoccare" the hours [= strike the hours, translator's note].

[20] This wheel is clearly depicted in f. 782 v [288 v-a].

[21] Hard to read: the last lines of the writing are quite confusing due to a hand moving over the fresh ink. The first letter of "tempo" (?) [= time, translator's note] doesn't look like a "t" and the box cannot be sustained by the time, but perhaps "per un tempo" [= all at once, translator's note], unless it is turns out that "tempo" has to be substituted by another word.

[22] Ms. "le", perhaps "le sue acque" [= the (plural) his (plural) waters, (literal translation, translator's note)].

Left column

- Shower that pours in a bucket hung to a pulley: seventh

- Same thing and a bell, with: b–a

As the bucket *a* in contact with the shower *b* fills up and gains the weight it ought to, it separates from the shower and moves very quickly one half braccio down. While separating from the opening of the shower, such opening of the shower closes with the help of the seventh proposition, and such bucket moves down and lifts the hammer with the order of the eighth and hits the bell, and immediately, the bucket, that has reached the ground, establishes itself in the order of the third and moves back up thanks to the hammer moving down and once it has reached the shower, it unlocks it with the order of the second, and this way it fills again and it again moves down with the same aforementioned rule, and it keeps going until its hours have rung.

- Small wheel with cogs, with: 1/3 – 25 – 25

- Bottom of a box, with: a – b – c – d

Bottom that has to open as *d* touches the ground; and releases all the water.

- Arithmetical operations

15	16	17	18
15	16	17	18
75	256	289	324
	96		
15	16		
225	256		
(225)			

Verso

Not visible before restoration, with no writing or drawings.

Folio 943

Recto

Formerly 343 v-a; ancient numbering 26 (in pencil) p; 259 × 196 mm.

Right column

* I wonder whether the float in equally deep water will come up to the surface quicker in wide water or in narrow water
* One has to wonder whether the float will come up to the surface quicker in deep water or in shallow water
* Moreover one has to wonder whether the float put at a certain depth will come up to the surface quicker in wide waters than in narrow ones.
In the wide ones, because it could be so narrow that it would produce no effect[23].

---

[23] Written in the margin, it is the answer to the preceding question.

- Illustration of water falling into water

The water that falls in a perpendicular line into running water, makes its penetration curve and curve will also be its coming up. The peak of the part that surges into the air, will not be in the middle of the "base"[24] of such boiling effect[25], and such "basa" will be oval.

Middle Column

- Cylindrical vases, with: b c d – a

These pipes will be made of thin clay and cooked for very long, until they become glass.

- Group of five vases

At the bottom of the vase place in front.

- Group of three vases

Vases of the hours. The first opens and then the water of the second, when it opens, moves through the first and this way it keeps going. But then think about what it will be that will have to close them. It will be the "baga" that each of those has inside.

- Large illustration in the center, with: n – m – t f – l – b a x – r y v – p o – d S – h K – g – q – e

* When the vase m will have filled the vase under it, the "baga" b will raise and the saddle[26] will unlock the piece of iron $v\,r$, so that the "baga" under $K\,h$ will move up as far as the Sd, until the piece of iron vr moves beyond the device ab and then such "baga" $K\,h$ will move away from $S\,d$ as far as $o\,p$, making a whole turn, and it will first hit with r the lever f and then with the lever v it will hit the lever t. At this stage the vase m won't be pouring any longer in the vase $t\,g$, but it will in all the other 23 vases; and when they will all be full, the water that will come forward will hit e and will drive m outside such "bottini" and won't be of any use, up until the 24 hours will have rung. Then this will be the last "bottino" to empty out and its water will hit q and will reposition the m vase straight so that it again pours in the vase $t\,g$, and this way it keeps going, until it is worn out; it is such that one can use it a lot and never needs to be adjusted.

Drawing of water clock … etc.

Verso

Not visible before restoration with no writing or drawing.

Folio 1011

Recto

Formerly 362 v-a; old numbering 28 (in pencil); little columns spaced 24 mm; for the gap at the bottom cfr. Clark-Pedretti III 49. Studies for a Water Clock, for which cfr. The ff. 65 v, 782, 941, 943, 1042.

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[24] If I understand the context correctly it might refer to the round concentric circles produced by an object falling in the water [translator's note].

[25] P. "bottino" unjustified: the water jumps into the air starting from a sort of own boiling.

[26] Ms. "la | sello"; the illustration shows a saddle shaped groove, on which lays the iron piece "v r".

- ▪ Right Margin

The containers for the hours must always have their bottoms lower on the front side and higher on the back, so that the water will always be able to flow away from the containers.

- ▪ Vases with water: a b c d—good invention

When the bringer turns itself to give water at the 23 vases, the bringer turns rapidly their 23 keys a b c d, which turns for a quarter of arc [90°], and so it closes them all. Then they open one by one when needed.

- ▪ Device for automatic opening and closing

This opens the key while going up and closes the key when it comes back.

Verso

Not visible before restoration, with no writing or drawing.

Folio 1042

Recto

Formerly 373 v-b; ancient being 29; 300×205 mm; transparent paper with a homogenous mixture. Construction of a water clock with ringer, cfr. ff. 65, 782. According to Beck, p. 650, this sheet contains the first ideas about this device.

Right column

- ▪ Figure, with: a

This is good for the way of opening the bottom.
Every container that fills itself, it fills by canal. The canal, when the container is full, closes, and the container of the first hour is the first that fills at the strike of the 24 hours, and it fills very soon, and then it takes an hour to empty and unload the container of the one hour, but there must be a first container that starts the other 24 containers.

- ▪ Figure of "container" with floating and hammer, and with: – d – n – p m a – e b

There is a leather bag that rises immediately to the surface of the water, when it unloads for the sixth time through the leather bag that rises, and the hammer strikes, striking it then opens the front of this box and the water immediately flows and straight after it closes.

- ▪ Towards the border, "container"

Make this vase is away from the canal, so that when it is closed, it doesn't drop in the original container.
The brick struck in the hand breaks, and doesn't hurt the hand.
The falling in many times makes the impression almost non existent.
The momentum of one part that moves, carrying a bigger part that wasn't moving before, just like the person who rises rapidly and while he was rising with his upper body the legs stood still, and then they move.

- Group of figures

  Clock that strikes the hours and rises 24 leather bags in 24 hours and each leather bag opens the container that rings the hours, and when that container is full, with the rule of the sixth, the leather bag is put in a little vase close to the container, and it opens immediately and flows the water of all the container which marks the hours.

- * Lower margin, group of figures, with

  o – a – b – c shower – opens the recipe – of the hammer – shower
  * *c b* rises, *b a* closes the shower with *a o* and unloads it.

- Left column
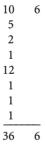
  When the hammer strikes the bell, and touches with the handle a spring, so that the hammer doesn't stop over that bell, because it would stop the sound after the strike.
  So it makes possible that the handle beat when the container unloads, since the hammer beat its strike; and so it goes on *(associated figures follows)*.

- Two figures, with: n ; c

  After the hammer has beaten the bell, immediately the bottom of the vase opens by the fourth proposition and immediately flows all the water who was within the vase. And this will be made with the movement of the leather bag *n* that after the strike still rises and unloads downside another leather bag united to the bottom of the vase.

- Column of numbers

10	6
5	
2	
1	
12	
1	
1	
1	
36	6

Verso

Not visible before the restoration, with no writing or drawing.
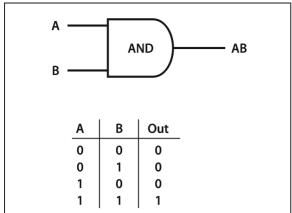
Appendix 2
Electronic Representation
of the Clock Operation

A fascinating way to study the Bell Ringer is in terms of modern electronics. Leonardo's Bell Ringer is hydraulic (it is driven and controlled by water under pressure), but more specifically it resembles a fluidic device. "Fluidics" was very popular beginning in the 1960s, the advantage being that power and logical operations could be combined in a single, fluidic, electroformed "circuit board." Even fluidic gyros had been developed. Advances in electronics and interfaces, to say nothing of the messiness of hydraulic fluid, brought about the demise of this technology by the late 1970s. Nevertheless, most electrical systems can be modeled as hydraulic or fluidic systems, and vice versa. Think of the following analogies:
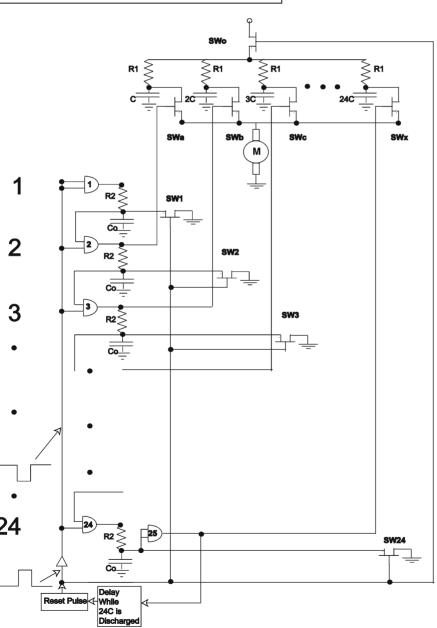
1. Water is guided via pipes or hollow tubes which conduct water easily and provide containment via an outer wall. Electricity is guided using metal wire, which conducts it easily and is contained by a non-conducting (insulating) outer wall.
2. Water is forced to flow by a pump or other source of pressure. Electricity is forced to flow with pressure, i.e. voltage from an electrical pump such as a generator or battery. Voltage is the pressure upon the electric "fluid," that forces it to flow.
3. A fixed amount of water can be measured. Similarly, we can specify a fixed amount of electricity or electric charge. One coulomb is a precise amount of electricity, just as a liter is a precise amount of water.
4. Flowing water is analogous to current. When flowing, water may be measured in gallons per minute (GPM). Electrical current is measured in coulomb per second or amperes.
5. Given the above, pressure and flow are the basic measures of both water and electrical systems.
6. The amount of flow for a given amount of pressure is determined by the resistance of the system to flow. In a water system, the resistance depends on the size of the pipe, the smoothness of the inside walls and valves which may be present, etc. In an electrical system, resistance is often determined by "resistors," which would be analogous to a constriction in a pipe.
7. Valves (a kitchen faucet is a form of valve) turn on or off the flow of water. Specialized valves can open and close several different sources of water. The electrical analog to a valve is the switch, such as a simple wall switch that turns a light on or off. Transistors are electronic switches that, upon receiving a voltage, cause a circuit to open or close.

A more complex switch is an "AND GATE," which is a basic building block of logic circuits used in computers. Leonardo's "bottino," the fluidic version of an "AND GATE," is perhaps the most fascinating part of his Bell Ringer components. The logic equation for an AND GATE is $Z = AB$ (Fig. A.1). In other words, to produce the output Z, two simultaneous signals, $A + B$, are required. If either A or B is missing, no Z output is produced. Leonardo's A signal is the line pressure; his B signal is the rising "baga," which turns on the "bottino's" valve. The single output Z is the pressurized fluid exiting the valve to enter the next "bottino".

Fig. A.1.
AND gate

The AND operation will be signified by AB or A·B. Other common mathematical notations for it are A∧B and A∩B, called the intersection af A and B.

A	B	Out
0	0	0
0	1	0
1	0	0
1	1	1

Fig. A.2.
Bell ringer electronic equivalent
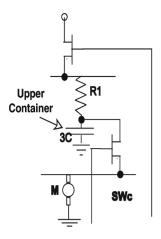
Fig. A.3. Bottini, capacitors

There are many ways to represent electronically the operation of the clock. For example, a single microprocessor could be used and programmed to perform all the functions of the clock. The example presented here uses discrete electronic components to represent the various components of the clock.

Figure A.2 shows one electronic version of the clock that depends on analog components. The bottini, illustrated in Fig. A.3, are represented by capacitors, C_o, and the restriction in the flow of water into these containers is represented by resistors, R_2. The 24 "container of the hours," shown in Fig. A.4, are represented by capacitors C, $2C$, $3C$, …, $24C$. Here the value of the capacitor nC is n times the value of C and holds n times the charge that C holds. Here again the restriction in the flow of water into these containers is represented by $R1$. We choose component values such that the time to fill capacitors C_o is much much longer than that needed to fill capacitors nC, i.e. the time constant $R2 \cdot C_o \gg R1 \cdot nC$.

Last, but not least, the Bell Ringer is represented by a motor **M**.

Operation

The reset pulse begins the operation. During the pulse, **AND** GATES **1** through **24** are turned off and no voltage is applied to the $R2C_o$ networks. At the same time, all charge on capacitor C_o is drained off by switches **SW1** through **SW24**. These switches are **MOSFET**s (**M**etal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistors) and are used because they require very little current to turn them on. It is the electrical field from the voltage applied to the gate that controls the current through the switch. One last operation is performed during the reset pulse. Switch SW_0 closes and fully charges capacitors **C** through **24C**. After the reset pulse the clock operation begins. **AND** GATE **1** is turned on and charges the first C_o. When the level of charge reaches a certain level two things happen. **AND** GATE **2** is turned on and charges the second C_o. At the same time, switch **SWa** is closed and drains the charge from capacitor **C** through the motor **M**. The motor **M** is designed to do work proportional to the electrical charge going through it. That is, if n times the charge flows through the motor, then the motor performs n times the work. The operation continues in like manner until all capacitors, C_o, are charged. At this point **AND** GATE **25** is turned on, which causes (1) switch **SWx** to close, which drains the charge from **24C** through the motor **M** and (2) the reset process begins.

Fig. A.4. Container of the hours, resistors

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Clara Bosak-Schroeder

The Religious Life of Greek Automata

This paper examines the religious lives of Greek automata. An automaton is an object that has been constructed to move on its own.[1] I argue that ancient Greek automata at first had a solely magical life, later attained a mechanical life, and that this change from magical to mechanical allowed automata to proliferate in religious contexts. While automata were originally imagined as purely magical, the advent of advanced mechanics later in antiquity made it possible for automata to be realized and also caused Greeks in the Hellenistic and Roman ages to reinterpret magical automata as mechanical. Later Greeks' projection of mechanical knowledge onto the magical automata of the past mirrors twentieth and twenty-first century scholars' tendency to reinterpret ancient automata as "robots" in line with technological advances in their own time. Changes in mechanics in antiquity and the response of people to those changes leads me to advance the concept of "relative modernism." I argue that modernism is a mind-set that recurs throughout history rather than one that emerges in a unique period of history.

From Magic to Mechanics

In common parlance, an automaton is a self-moving or self-operating machine. In historical and literary studies, "automaton" is used especially to designate those self-operating machines that were created before the twentieth century. These include Leonardo da Vinci's fifteenth-century "mechanical knight," Jacques de Vaucanson's eighteenth-century "digesting duck," and the many clock-work dolls, animals, and music boxes of the nineteenth century.[2] Though no automata survive from classical antiquity, we do have ancient texts that describe them.[3] The oldest of these appear in Homer's *Iliad*. In *Il.* 18, Thetis enters Hephaestus' workshop to commission new armor for Achilles, and finds the god already hard at his characteristic work:

> [Hephaestus] was making tripods, twenty in all, to stand around the sides of his well built hall,
> and below the base of each one he set golden wheels so that of their own accord [*automatoi*]

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1 LSJ, s.v. *automatos* (2). Some Greek *automata* (both natural and artificial) are associated with the *automatos bios*, or golden age; see Ruffell 2001 and Baldry 1953.
2 For the history of automata, see Kang 2011 and Reilley 2011.
3 See Humphrey, Oleson, and Sherwood 1998 for further reading in Greek and Roman automata. For the purposes of this paper, I will not treat "living statues," i.e., statues that come to life, for which see Francis 2009, Spivey 1995, Morris 1992: 215–238, and Freedberg 1989: 283–316.

they could enter the divine assembly and again return home, a wonder to behold (*Il.* 18.373–377).[4]

The tripods are "a wonder to behold" because they are *automatoi*, self-moving. Hephaestus is outfitting the tripods with wheels so that they can return to him automatically; he will not have to carry or wheel them back himself. A little later in the scene with the automatic tripods, Hephaestus stops his work and approaches Thetis with the help of golden maids:

> Golden attendants in the form of living maidens moved quickly to support their lord. They have sense in their hearts, and speech and strength, and know handiwork from the deathless gods (*Il.* 18.417–420).[5]

Like Hephaestus' tripods, the golden maids are also automata, but they demonstrate an even greater degree of functionality since they not only move when bidden, but possess sense and reason to anticipate their master's needs. As we learn from Homer and Greek mythology at large, Hephaestus is lame, and needs the maids' help to move from place to place in his workshop.[6]

The automata in *Il.* 18 were obviously fictional at the time of the poem's composition. Although we have very old tripods from ancient Greece that survive in the archeological record, they certainly do not move of their own accord, nor do we have any evidence that the Greeks of Homer's time could have built an automatic tripod.[7] Yet we do have ancient Greek instructions for the building of real automata, the best-known of which date from the first century C.E. writer Heron of Alexandria.[8] His writings cover a range of topics, from hydraulics and mechanics to optics and artillery

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4 Translations are mine. All texts are taken from the TLG except where indicated.
...τρίποδας γὰρ ἐείκοσι πάντας ἔτευχεν
ἑστάμεναι περὶ τοῖχον ἐϋσταθέος μεγάροιο,
χρύσεα δέ σφ' ὑπὸ κύκλα ἑκάστῳ πυθμένι θῆκεν,
ὄφρά οἱ αὐτόματοι θεῖον δυσαίατ' ἀγῶνα
ἠδ' αὖτις πρὸς δῶμα νεοίατο θαῦμα ἰδέσθαι.
5 ... ὑπὸ δ' ἀμφίπολοι ῥώοντο ἄνακτι
χρύσειαι ζωῇσι νεήνισιν εἰοικυῖαι.
τῇς ἐν μὲν νόος ἐστὶ μετὰ φρεσίν, ἐν δὲ καὶ αὐδὴ
καὶ σθένος, ἀθανάτων δὲ θεῶν ἄπο ἔργα ἴσασιν.
6 Francis 2009 notes the connection between the golden maids and Hesiod's Pandora. The giant Talos is another human-like automaton in Greek literature, for which see Buxton 1998. For the stationary guardians Hephaestus constructs, including the dogs that guard Alcinous' palace, see Faraone 1987.
7 Most extant tripods are stationary, but Morris 1992: 10 notes several (non-automatic) wheeled versions. See especially Catling 1964: 207, pl. 36.
8 For the evolution of mechanics from the fourth century onward, see Drachmann 1963, Lloyd 1973: 91–112, and Cuomo 2000: 97–104. Aristotle provides some of our earliest references to real automata, for which see Berryman 2009: 71–73, De Groot 2008, and Bianchi 2006.

construction, and most were transmitted in their original Greek, though some survive only in Latin or Arabic translation. Because Heron relied on the work of earlier engineers, although to what extent is not clear, it is hard to date precisely the technology in his works.[9] None of Heron's automata survive, and so there is no proof that he himself constructed the devices he describes. But modern reconstructions show that his automata, even if never built, could be built and would have functioned as promised.[10]

In his treatise *Spiritalia Pneumatica* (*Spir.*, hereafter), for example, Heron tells readers how to build 78 devices that are powered by compressed water or air. Because these devices are elaborately ornamented and have limited time- and labor-saving applications, scholars have often dismissed them as "toys" or "gadgets."[11] It is true that some of the entries in the *Spir.* demonstrate different pneumatic principles, different kinds of siphons, for example, and would have been of primary interest to those with an academic investment in mechanics. Others, however, seem designed for social use, and of these, several have sympotic overtones. The twenty-fourth entry of the first book (= Woodcroft 24), for example, describes a device that mixes wine and water in desired proportions. While it has been convincingly argued that these wine-pouring and mixing devices were designed for private, elite consumption,[12] others are suited to a larger ritual, religious, or theatrical context.[13] These include an automatic holy-water dispenser (1.21 = Woodcroft 21)[14] and temple door-opener (1.38 = Woodcroft 37), as well as a number of figural automata, including whistling birds (1.15 = Woodcroft 15), drinking animals (1.30 = Woodcroft 30), and one of Heracles that, when it shoots an apple, causes a snake to hiss (1.41 = Woodcroft 40). These could be kept in miniature form for private entertainment, but also adapted to larger tableaux, such as Heron describes in the *Automatopoetica* (*Aut.*, hereafter). In this work, Heron provides instructions for building two elaborate scenes, one in which Dionysus and his followers dance and pour libations, the second which stages the story of Nauplios.

Whether Heron expected a temple to use his automatic door-opener or holy-water dispenser is impossible to say, but we know that a figural automaton like those in the *Spir.* appeared in Ptolemy Philadelphus' third-century BCE Grand Procession. This magnificent parade included statues of Dionysus and scenes from his life,

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9 For the dating of Heron and his relationship to his predecessors, see especially Drachmann 1948: 74–81. See Boas 1949 For Heron's influence on sixteenth- and seventeenth-century mechanics. Tybjerg 2005 discusses Heron's reworking of his sources.

10 See Woodcroft 1851 and Schmidt et al. 1899 for examples. Tybjerg 2005: 216 notes Heron's emphasis on the physicality of the devices and the reader/builder's sense-perception of them, which may indicate that the devices were in fact constructed.

11 Tybjerg 2003: 444, n.5 catalogues these dismissals.

12 Schürmann 1991: 158–220.

13 Tybjerg 2003, Schürmann 1991: 223–249, Murphy 1995.

14 The first number refers to Schmidt et al. 1899, the second to Woodcroft 1851.

as well as an automaton of his nurse, Nysa, dressed in Bacchic costume that sat, stood, and poured milk libations.[15] This automaton might not have been truly mechanical,[16] but it is reasonable to think that Heron was both inspired by the form of this automaton and intended his treatises to contribute to the proliferation of automata in royal processions. Processions would be ideal for showing off the tableaux in the *Aut.* and for combining the smaller figural automata of the *Spir.*

The fact that the automaton in the Grand Procession appeared in the Dionysiac section of the parade is also significant for understanding Heron's automata. Several of the devices refer to Dionysus directly (the whistling thyrsus at *Spir.* 2.9 (= Woodcroft 48); the tableau of Dionsysus and Maenads in the *Aut.*), while others feature wine-pouring, including *Spir.* 1.37 (= Woodcroft 36), which features a Satyr, the god's typical companion. As the emphasis on Dionysus in the Grand Procession makes clear, the god was very popular with the Ptolemies; they traced their lineage from him and used Dionysus' association with Alexander the Great to further legitimize their reign.[17] Heron's use of Dionysiac imagery is most likely a legacy of his predecessors, many of whom worked under Ptolemaic patronage.[18] Yet the fact that his treatises reuse this imagery implies that Heron expected Dionysus-themed automata to retain their appeal. The more recent memory of Cleopatra and Antonius's use of Dionysus in their self-promotion may account for this.[19]

The Dionysiac imagery in Heron's treatises may play on another sort of association between Dionysus and automata as well. Although Bonner ultimately rejected the idea, he proposed a connection between Dionysus' spontaneous gift of wine (*h. Hom.* 7.35) and wine and milk (*Ba.* 141; 704 ff.), and Hesiod's golden age, when the earth spontaneously (*automate, Op.* 117) bore its fruit.[20] If this association between Dionysus and the golden age were felt in antiquity, a device that automatically produced wine and milk would play on the application of the word *automatos* to both mythic crops and machines. We know that Dionysus' worshippers re-enacted his miraculous providence at festivals, producing wine and milk through, as Bonner 1910 says, a "pious fraud." Automata that seemed to produce wine spontaneously, as

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15 Rice 1983 provides a text, translation, and commentary of Athenaeus' description of the Procession. See pp. 62–68 for the Nysa automaton in particular. Leslie Day has suggested that the Karphi goddesses with swinging feet (Pendlebury 1937/8: pl. 31) were used in processions (public comment). While not automatic, these figures might have been a precursor to Nysa and other processional automata.

16 But see Schürmann 1991: 243–245. As Tybjerg 2003 says, "Hero ... may thereby be seen as providing the know-how behind the massive display of religious and secular power featured by the Grand Procession" (462). I wonder whether the cave that gushes milk and wine (*Ath.* 200c) was also mechanical. Polybius 12.13.11 tells us of a snail automaton that appeared in a procession for Demetrius of Phaleron. See Schürmann 1991: 239–240.

17 Rice 1983: 83–86, Tondriau 1946, Pamias 2004.

18 Schürmann 1991: 13–31.

19 Hazzard 2000: 152–153.

20 Bonner 1910. Gatz 1967: 177 includes the Bacchae in his concept of the golden age.

many of Heron's do (including the tableau in *Aut.* that gushed wine and milk), could be used for the same purpose. As Bonner 1929 implies, the Nysa automaton in the Grand Procession and Heron's automata might have been replicating, in a more convincing way, a ritual that was usually performed by human beings.[21]

In private gatherings of elites, Heron's automata would have been examined closely and perceived as "wonderful" in a playful sense.[22] But when viewed in public, in processions or festivals, his devices could have produced a wonder more akin to awe or fear. To see a device produce wine and milk would have made Dionysus seem truly present, and would have accorded his powers to those who had produced the automaton. Even those automata that were not associated with Dionysus would, in public display, evoke literary automata that were divinely animated, like Hephaestus' automata in *Il.* 18. Although metal-working connotes science today, in the ancient world it was associated with magic, and Hephaestus was seen as a magician.[23] In a religious context where miracles were at least theoretically possible, automata that made those miracles seem real would have been a powerful tool for instilling religious awe.[24]

Advances in mechanics thus allowed automata to proliferate in religious contexts, and the imagery with which Heron adorns his automata suggest that he anticipated religious uses for them. For those unaware of recent developments in mechanics, these automata would seem magical, just as Hephaestus' automata were magical. There is evidence that this was not an unintended side-effect of the device's construction, but part of their purpose: Heron was both aware of the fact that his automata would be largely understood as magical and played up this fact in their design. Karin Tybjerg points out that Heron repeatedly tells the reader how to keep the mechanism of the automata a secret; he instructs his readers to "hide" (*kruptein*) key features of the automaton or make sure the mechanism remain "unseen" (*aphanes*).[25] An entry in the *Spir.* for a drinking animal automaton offers a clear example:

> In any place where there is running water, [make] an animal of bronze or some other material. And when it is offered a cup, it [will] drink with a noisy slurp [lit. noise and bellow], so as to produce the appearance [*phantasia*] of thirst ... Let the mouth of the animal be at R, through

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21 Bonner 1910: 182, Bonner 1929: 373; Nilsson 1906: 291–293. The main textual witnesses are Pausanias 6.26, Pliny 2.231; 31.16, and Diodorus 3.66. As Diodorus says, "καὶ Τήιοι μὲν τεκμήριον φέρουσι τῆς παρ' αὐτοῖς γενέσεως τοῦ θεοῦ τὸ μέχρι τοῦ νῦν τεταγμένοις χρόνοις ἐν τῇ πόλει πηγὴν αὐτομάτως ἐκ γῆς οἴνου ῥεῖν εὐωδίᾳ διαφέροντο."

22 For wonder in Heron's own discourse, see Tybjerg 2003.

23 Blakely 2006, Faraone 1987, Graf 1999.

24 Tybjerg 2003: 458 argues that Heron associates himself with Hephaestus' cunning; this association would extend to those who built the automata as well.

25 Tybjerg 2003: 451.

which a concealed [*kruptes*] pipe runs along one of the animal's feet or some other part into the base; let the pipe be RST (Heron, *Spir.* 1.29 = Woodcroft 28).[26]

In order for the automaton to produce the appearance, *phantasia*, of thirst, the pipe through which it sucks up water must be hidden from view. We can see from this passage that mimicry is essential to Heron's device and to the automaton as he conceives of it. Automata replicate processes that were otherwise associated only with animate beings. For this replication to work, the mechanism behind the automaton must remain out of sight.

Tybjerg does not discuss this passage of the *Spir.*, but it supports her conclusion: "By hiding mechanisms ... Hero[n] creates a boundary between the unknowing spectator and the knowing mechanician. He thereby places the mechanician in an epistemically superior position because he can see the causes of the movements and the spectator cannot."[27] As Tybjerg notes, it makes sense that Heron would want to hide the mechanism of his automata from most people. Making these devices seem magical makes Heron seem like a magician, maybe even a divine magician like Hephaestus, and it allows those who build and use his automata to associate themselves with Hephaestus' powers.[28] This does not mean that Heron himself saw the devices as magical—indeed, his entire work aims at demystifying the wonderful for his readers while he simultaneously maintains it for uninitiated viewers—but this effort itself assumes that demystification is necessary, and that perpetuating the devices' magical appearance is desirable. Heron does not so much take a philosophical stance towards the (un)reality of magical phenomena as he recognizes how his devices will be seen, and how he wants them to be seen.[29] The word *phantasia* is crucial to this distinction. Although usually translated as "appearance" (as I have done here), in Plato *phantasia* is the useful (if also fallible) knowledge we attain by sense-perception, especially sight.[30] Heron's *phantasia* is precisely that: an appearance that convinces the mind of one reality while obscuring another.

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26 Κατασκευάζεται δὲ ἔν τινι τόπῳ ὕδωρ ἐπίρρυτον ἔχοντι ζῷον εἴτε χαλκοῦν εἴτε ἐξ ἄλλης τινὸς ὕλης· προσενεχθέντος δὲ αὐτῷ ποτηρίου πίνει μετὰ ψόφου καὶ βοῆς, ὥστε φαντασίαν ποιεῖν δίψης ... τὸ δὲ τοῦ ζῳδίου στόμιον ἔστω πρὸς τῷ Ρ, δι' οὗ σωλὴν κείσθω φέρων δι' ἑνὸς τῶν ποδῶν ἢ δι' ἄλλου τινὸς μέρους τοῦ ζῳδίου κρυπτῶς εἰς τὴν βάσιν· ἔστω δὲ οὗτος ὁ ΡΣΤ.
27 Tybjerg 2003: 451.
28 Hiding the mechanism might also excite Greek anxieties about the improper use of *techne*. See Cuomo 2007: 29–34 for "the trouble with *techne*."
29 Tybjerg 2005: 214, n. 41 notes Heron's allusions to different philosophers and their theories.
30 Watson 1988: x, 1–13. Aristotle extends *phantasia* to some nonhuman animals and gives a different account of its mechanics, but does not alter Plato's definition in a way that concerns us here. See Watson 1988: 14–37 and Sheppard 2014. Heron uses *phantasia* comparably at *Aut.* 30.5. In *Definitiones* 135–138, the final sections of his mathematical work, *phantasia* means something closer to "imagination," as was often the case in later philosophy, but these sections are considered spurious. See Giardina 2003.

The advent of advanced mechanics gave rulers a reason to build religious automata and exploit the ability of automata to mimic magic, but advances in mechanics also created a rift within the concept of the automaton itself. Though Heron designed his devices to remain mysterious and magical to most spectators, engineers who could use Heron's instructions to fabricate mechanical automata knew that they were not magical at all. This knowledge caused at least some of them to reinterpret the magical automata of the past as mechanical. The bT scholiast says of Hephaestus in his workshop:

δῆλος δέ ἐστιν εἰδὼς μηχανικήν.

It is clear that [Hephaestus] knows mechanics (bT on *Il.* 18.373).[31]

Although the adjective form of *mechanike* means merely "resourceful" or "inventive," the noun form is found only after the fourth century BCE, when mechanics had developed into a complex discipline.[32] When the bT scholiast says that Hephaestus knows *mechanike*, mechanics, he means the sort of mechanics that Heron had access to, not those that were known to Homer. The bT scholiast has projected the technology of his own time onto the automata of Homer's time, transforming Hephaestus from a magician into a mechanic and the automatic tripods from magical creations into works of engineering.

As E.R. Dodds has said, quoting the words of Jacob Burckhardt, "'rationalism for the few and magic for the many,' might on the whole be said of Greek religion from the late fifth century onwards."[33] The same situation pertained to Greek engineering from at least the first century CE onward. Those who read Heron and similar treatises rationalized works of divine engineering in Homer just as their counterparts in natural philosophy rationalized Homer's gods. But the majority of Greeks who heard or read the Homeric epics and saw one of Heron's automata in action probably maintained a magical understanding of both Heron's automata and Homer's.

Lest this sound too much like a recapitulation of Nestle's *Vom Mythos zum Logos* (1940),[34] I must highlight the incomplete and dynamic nature of mythic and mechanical understandings in antiquity. Magic for the many is what the mechanician wanted, perhaps what his patrons wanted, too. Furthermore, the ignorance that would lead Hellenistic spectators to interpret mechanical automata as magical also ensured that they would continue to interpret literary automata, including Hephaestus' creations in *Il.* 18, as they were originally written to be understood. Mechanical automata succeed magical ones in time, but mechanics is not the *telos* of objects that move of their own accord. Magic is often dismissed as false or erroneous science, as a system

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31 The bT scholia transmit material that ranges from Alexandrian to late antique. For dating, see Dickey 2007: 19–20. For the worldview of these scholia, see Schmidt 1976.

32 Schürmann 1991: 33–38.

33 Dodds 1966: 192.

34 Buxton 1999: 1–24 chronicles the history of this work and its reception.

of explanation that people fall back on in the absence of science.[35] Magical explanations do sometimes give way to scientific ones, as when automata go from being magical and fictional to mechanical and realizable. But the bT scholiast demonstrates that science is also sometimes false or erroneous magic; that science imposes itself into magical situations, like Hephaestus' workshop, because mechanical knowledge has deprived readers of the ability to see things magically.

Automata and Modernity

The fact that advances in mechanics within antiquity changed how people could and sometimes did see automata has an analogue in classical scholarship. In current scholarship on automata, there is both a tendency to call ancient automata "robots" and a concomitant tendency to say that "robot" is an inaccurate term for ancient automata. Hephaestus' automata are "robotic" (Lively 2006: 279), Heron describes "automi-*robot*" (Cambiano 1994: 624), and "Hephaestus create[s] robots to serve the gods" (Humphrey, Oleson, and Sherwood 1998: 61). Considering this phenomenon alongside the reinterpretation of automata within antiquity reveals a shared aspect of human cognition, the tendency to project one's own technology backward in time.

Robots, in current parlance, are more advanced automata. Engineers will say that robots function electronically and are programmed by computers, neither of which was possible before the mid-twentieth century; thus, English-speakers today use "robot" to describe electronic and computer-programmed automata. But the terms "automaton" and "robot" are slippery, and while electronics and computer-programming furnish neat criteria by which to differentiate automata from robots, these criteria are also somewhat arbitrary. Pierre Jaquet-Droz' 1774 Writer automaton, for example, though not computer-programmed, can be programmed by hand. Should it therefore be classed as an "early robot" or "proto-robot" rather than a "complex automaton," which is how it is usually described? Nevertheless, this is the terminology as we have it.[36]

The problem of what to call Heron's creations is relatively simple. He himself called many of them, in Greek, *automata*. The Greek word *automaton*, which describes a self-moving object, is very close to the English derivative, which describes a self-operating machine; there is a good fit between the English use of this word and Heron's. Furthermore, Heron's automata are materially very similar to the automata of the Mediterranean middle ages, Renaissance, and early modern period. Like them, Heron's automata are powered by mechanical processes; pneumatics is a sub-type of mechanics. Scholars who call Heron's automata "robots" are guilty of failing to en-

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35 For the relationship between magic and science, see Lloyd 1979, Dickie 2003, and Collins 2008. On the issue of ancient belief in what today may seem unbelievable, see Lehoux 2012.

36 See Voskuhl 2013 for the Jaquet-Droz workshop. Sharkey 2007 suggests that one of Heron's automatic theaters might also have been programmable.

force the difference between self-moving machines that operate electronically and have been computer-programmed (robots) and those that do not (automata).

The problem of what to call Homer's automatic tripods is more vexing. Although self-moving, Hephaestus' creations cannot have been thought to function mechanically at the time of the poem's composition. As Sylvia Berryman says:

> [Stories like Homer's] should not be read as evidence, then, that the creators of this early literature imagined the building of 'mechanical' automata. This is not only because there is positive evidence to suggest that divine animation is needed: it is *a priori* unreasonable to expect mechanical conceptions before the development of mechanics ... We should not expect people to be able to *imagine* what devices can actually achieve, without practical experience ...While it may be tempting to read accounts of 'statues that move' as anticipating modern robots, this is not warranted, unless there is evidence of technology available that could give some content to such a conception. It would be risky to assume the conceivability of techniques that were only developed later, and to suppose that the ancient storyteller must be imagining something comparable. What seems possible to us may have seemed to an ancient to require intervention by divine or supernatural agency.[37]

Berryman argues that scholars cannot understand Hephaestus' automatic tripods as anything like later mechanical automata, let alone electro-mechanical robots, because there was not mechanical technology to inspire these literary creations at the time of the poem's composition. One might object that Berryman's argument does not allow writers to imagine anything new. For her, there has to be real, on-the-ground technology in order to inspire stories about technology. But setting that reservation aside, her conclusion, that "what seems possible to us may have seemed to an ancient to require intervention by divine or supernatural agency" is certainly true, especially of the automatic tripods and golden maids of *Il.* 18. They are Hephaestus' creations, and while we are not told how he animates them, there is no reason to believe that Greek readers before the advent of advanced mechanics would have understood them as governed by reproducible mechanisms. To the contrary, Christopher Faraone has argued convincingly for Hephaestus' associations with magic in general and with the magical animation of automata in particular.[38] Hephaestus' tripods are divine creations that operate by magic, not mechanics. The first Greek automata are thus as far from being robots in a material sense as they can be; they are someone's creations, true, but they are magical creations, not applications of reproducible science.

I suggest that scholars who conflate the magical and mechanical in ancient sources are not applying a worked out theory of automata and robots (one that would, perhaps, question the common association of robotics with electronics and computers), but are, rather, revealing an unconscious outcome of human cognition, the result of how having technology changes the way people see the world. When scholars

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37 Berryman 2009: 27–28.
38 Faraone 1987. See also Blakely 2006, Graf 1999.

call Hephaestus' tripods "robots," they are absorbing these objects into their own technological frame of reference. Because they live in a world in which electronic, computer-programmed robots do exist, they have a tendency to project this technology onto objects that look similar to them. In one sense, this phenomenon could be considered a species of what G.E.R. Lloyd has called "argument by analogy,"[39] but I am saying something more specific than that people today understand ancient automata by analogy to the robots in their lives (or fantasies). Moderns absorb ancient automata into the category of the robot even when they have every reason to observe the distinction between the two—even when, for example, they are scholars who are attuned to the important differences between ancient Greeks, Romans, and themselves. Understanding ancient automata by analogy with modern robots is an understandable first move, but it is sustained in the scholarship because there is something special about how technology changes perception. Once humans come to possess a technology, it is very hard to unsee it. This explains why even Hephaestus' automata, which most scholars know were originally understood magically, are nevertheless rationalized and called robots in the modern literature.

This process, by which people project their technological understanding onto the past, happened also in antiquity when technology changed. Berryman is right that Hephaestus' tripods were not originally understood mechanically, but mechanical automata did come into existence later on in antiquity, by the first century CE at the latest, as we know from Heron. While Homer's original audience would have understood the tripods as having divine and magical life, Heron's readers and anyone else familiar with mechanical automata could have reinterpreted Hephaestus' magical creations and projected their own mechanical understanding of automata onto these objects. The bT scholiast, who noted that Hephaestus must have known mechanics, does just that.

When Berryman took her colleagues to task for calling ancient automata "robots," for projecting their own technological understanding backwards, she said, quite rightly, that "what seems possible to us may have seemed to an ancient to require intervention by divine or supernatural agency." But although true enough for the Greeks of Homer's time, this sentence pits us, the moderns, against them, the ancients and erases technological change within antiquity. As Bruno Latour has said, "The adjective 'modern' designates a new regime, an acceleration, a rupture, a revolution in time. When the word 'modern', 'modernization', or 'modernity' appears, we are defining, by contrast, an archaic and stable past."[40] But the past was not stable, as we have seen.

Technology changed within antiquity, and with that change came new understandings of the things of the past. If we take ancient technological change seriously and consider how it affected people, then it is no longer appropriate to pit us against

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39 Lloyd 1966.
40 Latour 1993: 10.

them, to pit modernity against antiquity as we are accustomed to doing. Instead, I suggest that we think of ourselves as one group of moderns among many, and consider modernism a mind-set, or a process that recurs throughout history, rather than as a single time period that forever opposes us to a monolithic past. If we do this, then modernism becomes something relative and dynamic. Not only are we modern with respect to Homer, but so are Heron and the bT scholiast. This is not only because both we and Heron and the bT scholiast understand mechanics, whereas Homer did not, but because we are all in a position to project our understanding backwards and outwards onto everything we see. As an example of relative modernism and in conclusion, I offer a scene from a more recent classic.

The fairytale of Beauty and the Beast usually involves a beautiful young woman whose father is imprisoned in the castle of the Beast, a man cursed into semi-animal form. The Beast frees the father in exchange for his daughter, whom he hopes will release him from the curse by loving the Beast as he is. In Disney's *Beauty and the Beast*, the father-figure, Maurice, is an inventor and his inventions play an important part in the movements of the plot.[41] He is traveling to a fair to display his automatic wood-chopper when he loses his way and washes up at the Beast's castle, and later, imprisoned by the evil Gaston (his daughter's suitor), he and his daughter, Belle, are freed by that same machine. Maurice, who himself invents automata, is a foil for the enchanted servants in the Beast's castle who have come to resemble automata by virtue of their enchantment. The housekeeper, Mrs. Potts, is now a teapot. Fifi the maid is now a featherduster. The two highest-ranking servants in the castle, Lumiere and Cogsworth, have been transformed into a candlestick and clock, respectively. When Maurice, lost on his way to the fair, enters the Beast's castle seeking shelter, Lumiere greets him.

"Incredible!" Maurice says, looking at Lumiere, and then picks up Cogsworth, winding, shaking, and examining him. "How is this accomplished?" he asks.[42] At first stupefied by the wonderful, "incredible" sight before him, he immediately begins to assimilate Cogsworth to his own technological frame of reference, asking how such a thing has been "accomplished," that is, brought into being by the kind of technology he himself possesses. When Maurice shakes and winds Cogsworth, he is behaving as Tybjerg's "epistemically superior mechanician," someone who has dedicated himself to inventing through mechanics what the enchantress of the Beast's castle has achieved with magic.

This scene is an analogy for the process at work when twentieth- and twenty-first century scholars read about ancient automata from their technological vantage point and when later Greek readers within antiquity, including Heron of Alexandria's readers and the bT scholiast, looked back on self-moving objects that were described in literature before they could be realized by human hands. *Beauty and the Beast* offers

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41 To my knowledge, this is the only version of the story in which this is so.
42 *Beauty and the Beast* 1991 DVD: 14.30; https://www.youtube.com/watch?v=JdzY6vFKLXs: 0:29.

a vivid example of modernity as a mindset rather than a particular time in history. Maurice is modern with respect to the Beast's castle and the enchantment it is under, even though to us he seems at most early modern (he occupies what looks like eighteenth-century France). He is modern not only because he has technological knowledge, but because he projects it onto everything he sees. Heron's readers and the bT scholiast are modern with respect to Homer; when they read *Il.* 18 in the light of mechanical treatises, they can ask, as Maurice does, "how is this accomplished?"

Arthur C. Clarke's famous third law, "any sufficiently advanced technology is indistinguishable from magic,"[43] is usually taken to mean that to people who understand things magically, technology seems magical. Heron was banking on Clarke's third law when he encouraged his readers to hide the mechanism of the automata he had designed. But we can understand the third law in reverse as well. To those who are sufficiently technologically advanced, magic can and probably will be reinterpreted as technology. This is a feature of modernisms across time, our modern condition and the modern condition of later Greeks within antiquity.

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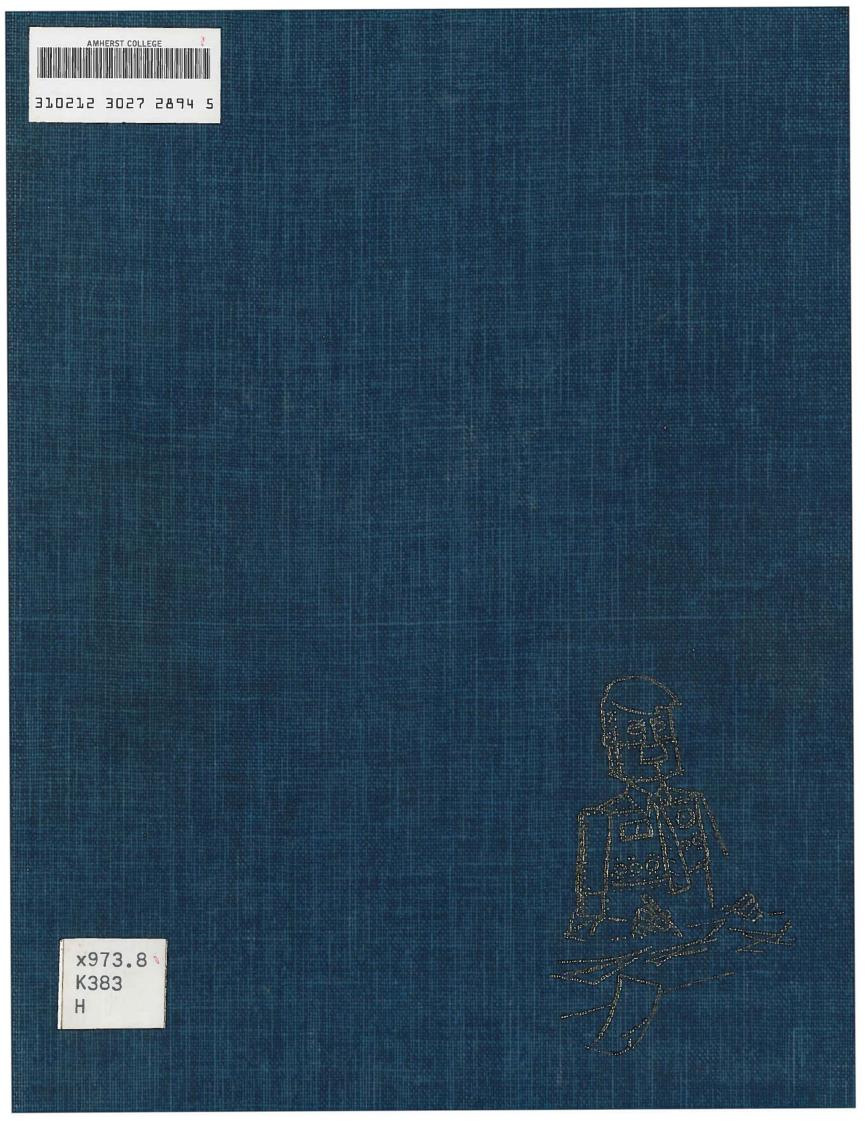
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43 Clarke 1982: 36.

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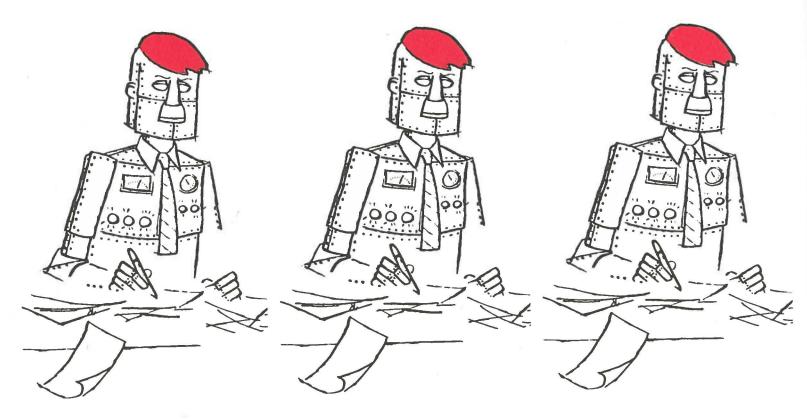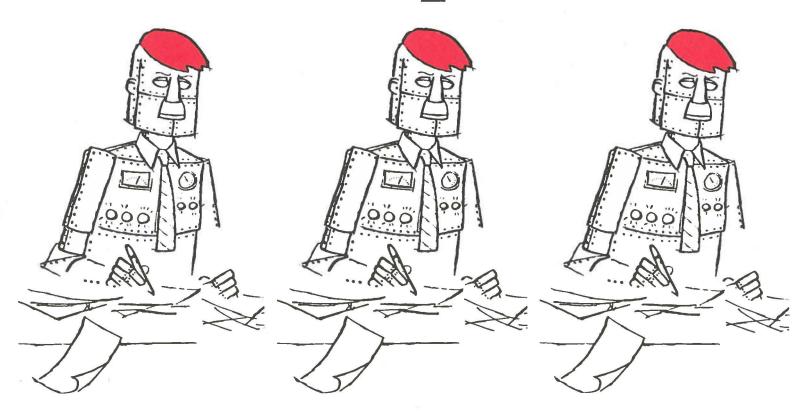
Kennedy's Robot Signs a Photograph for His Master

THE ROBOT THAT HELPED TO MAKE A PRESIDENT

the robot that helped

to make a president

A RECONNAISSANCE INTO THE
MYSTERIES OF
JOHN F. KENNEDY'S SIGNATURE

By Charles Hamilton

New York: 1965

Books by Charles Hamilton

Cry of the Thunderbird: The American Indian's Own Story
 (Macmillan, New York, 1950)

Men of the Underworld: The Professional Criminal's Own
 Story (Macmillan, New York, 1952)

Braddock's Defeat (University of Oklahoma, 1959)

Collecting Autographs and Manuscripts (University of
 Oklahoma, 1961)

Lincoln in Photographs: An Album of Every Known Pose
 (University of Oklahoma, 1963, with Lloyd Ostendorf)

The Robot That Helped to Make a President (New York,
 1965)

Pamphlets by Charles Hamilton

The Strange History of . . . Franklin D. Roosevelt (New
 York, 1947)

Nine Poems (New York, 1961)

The Ship of Night (New York, 1963)

To my wife
DIANE
who aided in every way to
make this a better book.

PREFACE

SUPPOSE THERE EXISTED IN THE WHITE HOUSE a robot which could write the President's signature swiftly and expertly, creating a fabrication so perfect that it would pass as authentic in any court of law?

— Such a robot could sign a document which might plunge the nation into war.

— Such a robot could sign mandates if the President were indisposed or absent or if he died and the news of his death were withheld.

— Such a robot could be a terrifying weapon in the hands of unauthorized persons.

It sounds like science fiction. Yet this unreasoning automaton actually did exist, somewhere in our Executive Mansion! It was classified as top secret, and some Presidential aides vehemently denied its existence.

Although its use was very limited, it remained, like the imitative skill of those private secretaries who put the President's signature to letters, a threat to American security.

The murder of President John F. Kennedy on November 22, 1963 also marked the "death" of his notorious robot.

INTRODUCTION

A FRIEND OF MINE OBSERVED RECENT-LY, "psychologists might find a great deal to theorize about if they were to study Kennedy's signature. It seems to me as though there is a curious immaturity to it—as if Kennedy were not sure of himself."

Certainly it is true that, even as President, Kennedy signed his name in a bewildering variety of ways, from hurriedly scrawled and illegible contractions to his entire name penned with almost Palmer-like fluency. He is the first great figure in American history to vary his signature according to whim.

If we were to follow the wild tangent of some of those scholars who lamely contend that Shakespeare never lived because his handwriting and the spelling of his name occasionally differ in the five known examples, then what must we say of Kennedy? Obviously the man was a myth!

The amateur chirographer might assume that, since Kennedy's signature varied so greatly, a robot or his secretaries could write it for him without detection. After all, since his signature was never the same, who could say for certain whether it was penned by a mechanical hand, a secretary or by Kennedy himself?

It was perhaps this false principle that led to the ill-advised policy for the Presidential aides to declare genuine every signature of Kennedy which was mailed from his campaign headquarters or the White House. But each robot signature followed its own undeviating pattern, and each

secretary eventually injected his own personality into every Kennedy imitation. This makes the proxy signatures very easy to spot!

Some of Kennedy's aides have admitted that he personally signed very few letters or documents. Shortly before the President's death, a distinguished political leader approached Kennedy's brother, Robert, the attorney general, asking:

"I wonder if you could spare something in the President's handwriting for one of my constituents who collects autographs."

Replied "Bobby": "I collect autographs myself and I have great trouble getting anything in his handwriting or persuading him to sign anything!"

Kennedy's signature is already the rarest of any President. Nearly every day I am offered letters or photographs bearing machine or proxy signatures, and I have the unhappy task of telling the owners that their treasures were not personally signed. Very often the letters and photographs which I am obliged to condemn as robot or secretarial bear authentications from members of the Presidential staff.

If the duties of the President are so overwhelming that he cannot personally attend to all of them, perhaps one answer to the press of work is for the President to sign absolutely nothing except important state papers and official documents, and those only with initials. Secretaries could sign—but not with the President's alleged signature—all his routine mail. Autograph seekers could be pacified with facsimile signatures and a polite letter of explanation.

But for White-House officials to deny that the robot was used (and even to identify robot signatures as authentic) or to claim that aides and secretaries never signed his name for him, is to throw open a whole new line of inquiry and cast doubt upon other statements issued for President Kennedy.

Charles Hamilton

CONTENTS

1 MAN OR ROBOT?

PICTURE A HUGE, FACELESS ROBOT which grips a fountain pen in claws of steel. At the push of a pedal, its hidden parts awake and its metal arm moves firmly and quickly over a sheet of paper to perform the very human function of scrawling a name:

Tirelessly the robot works, signing thousands of letters, papers and photographs.

This is the remarkable automaton which for more than seven years relieved Kennedy of his burden of writer's cramp and helped him to reach the highest office in the world.

The margin of Kennedy's victory over his opponent Richard Nixon was very small—so small that the good-will created by letters signed by the robot may have won him the office of President.

Many Presidents have used steel- or rubber-stamp signatures—Andrew Johnson, Woodrow Wilson, Theodore Roosevelt and Franklin D. Roosevelt among them—but no

chief executive before Kennedy employed a robot to sign his name.

Nearly a century and a half ago Thomas Jefferson invented the polygraph, a machine which, in response to the movement of a master-pen in the hand of the writer, would start a whole row of pens and simultaneously sign a dozen or more documents.

But the "tin man" indentured to Kennedy was entirely different. Kennedy would write a "master" or "guide" signature to serve as a pattern. The master signature was then transferred to a matrix and adjusted in the automaton. Each time the robot was motivated by the pressing of a foot pedal, the pen moved swiftly across the page in a pre-coordinated pattern, writing a perfect signature. Although the pattern was identical for each signature, there were sometimes tiny differences between signatures of the same pattern because the operator moved the paper slightly during the signing process or because a different pen was used or the pen failed to leave an even ink deposit. Yet portions of each signature may be superimposed perfectly over comparable portions of other signatures of the same pattern.

Six different robot signatures are known at present. Five are patterned from original signatures of Kennedy. The sixth is probably from a Kennedy imitation furnished by an aide.
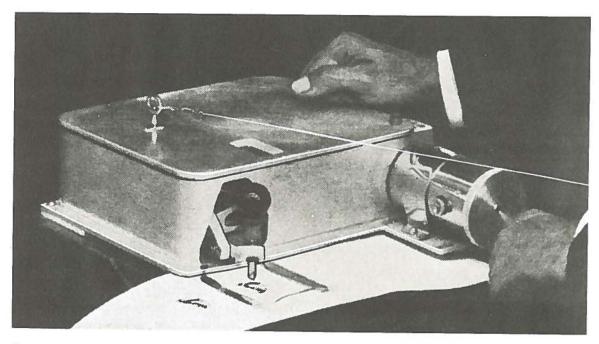
The six patterns are here reproduced on a loose sheet of tissue paper so that you can place them over the corresponding illustrations and see precisely how the robot signed Kennedy's name—each time with the same pattern, yet with minute variations which give an educated personality to the machine. (But the robot never learned the three R's —only one of them!)

According to Dr. James T. Culbertson, author of *The Minds of Robots*, it is conceivable that automata could develop consciousness or sense perception which might influence their behavior. If this had happened with Kennedy's

robot, the horrors of Capek's R.U.R. might have moved from the world of dramatic imagination into the world of political reality!

The Story behind Kennedy's Robot

The idea of creating a robot which could imitate the human skill of writing dates back to the ancient Arabs, but

Signo invented by P.-M. Durand (1916)

it was not until the eighteenth century that Friedrich von Knaus, regarded by his contemporaries as a great inventor, devised a successful mechanical writer. The French magician, Robert Houdin, also a noted mechanic, experimented with a similar machine; and P. T. Barnum had in his museum a robot penman which was destroyed in the great New York fire of 1865. In 1916 a French inventor, P.-M. Durand, devised a machine which he called the "Signo," pictured on this page, an automaton very similar to the

robot used by Kennedy. Later the Signo was incorporated in a human effigy romantically known as "Professor Arcadius" which could write and sign perfectly an entire sentence!
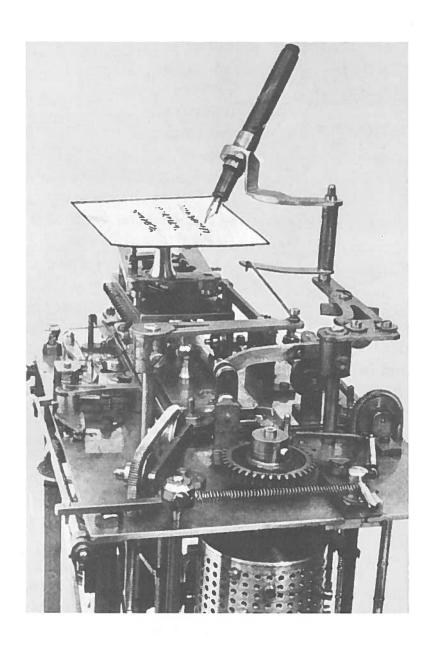
Dans un bon lot de qualités

attention à la persévérance

Arcadius

Handwriting and signature of "Professor Arcadius."

Imagine! with such a device installed in the figures of Mme. Tussaud's wax museum, the colorful personalities of the past, from Washington to Kennedy, could all scribble for visitors authentic replicas of their signatures! Robespierre could again sign the death warrant of Danton, and Lincoln could once more set free the slaves with a bold signature to the Emancipation Proclamation!

Writing Machine Invented in 1946 by M. F. Wiesendanger

Powered by an electric motor, this complicated device operates a fountain pen with almost human skill. The writing pattern is first set by an adjustment of the screws in the large cylinder. The machine then writes not only a signature but a complete, brief text!

The Type of Robot Used by Kennedy »→

"A fountain pen come to life" is the apt description of this amazing mechanical writer by its manufacturer, the International Autopen Company of Arlington, Virginia.

The Autopen can turn out as many as 3,000 signatures in a single eight-hour day from a "master" signature on a matrix, each an exact reproduction of the original. A dial regulates how swiftly each signature is written. At its lowest speed, the robot signs about as fast as the average man; but at top speed, it signs twice as swiftly as any human can write.
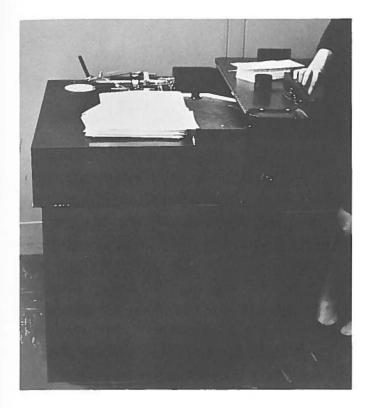
The "Model 50" Autopen, of which more than 200 are now used in the United States government offices, is believed to be the identical model employed by Kennedy. Because of the confidential task assigned to these robots, however, the names of their employers are, with a few exceptions like the FBI and the Democratic National Committee, kept darkly secret. I have discovered also that the machine is or was used by Robert F. Kennedy and Richard Nixon.

A foot pedal activates the Autopen, leaving the operator's hands free to feed in letters or documents. Or the robot can be placed "on automatic," and will continue to sign at brief intervals as fast as the operator can push letters under the pen. There is a lighted glass disk directly beneath the pen; and before using any signature pattern, the operator allows the pen to write on the glass. This temporary signature reflects through the paper and acts as a guide for placing each letter or document in exactly the right place.

According to the International Autopen Company, the robot writer "is as legal as though you had signed the paper yourself." They cite as an example that a state bond issue was signed by the machine, and the state's attorney-general passed upon the legality of the signature.

Provocative, is it not? Since a document or letter signed by the robot has been ruled legal, could the tin man continue to sign legally after his owner's death? And if a matrix were made from a genuine signature of Washington to be executed by the robot with a quill pen in authentic ink of the period on old hand-laid paper would it be considered authentic—or would it be a forgery? Or what would it be?

The Automatic Signature-Writing Machine
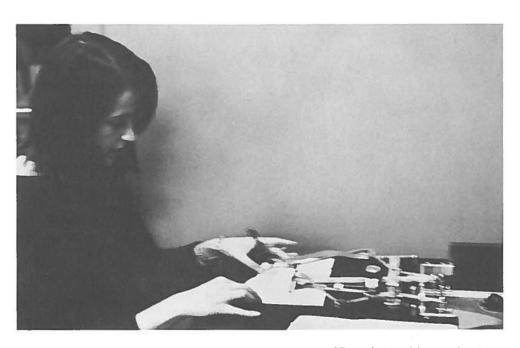

Full view of the machine

Activating the robot by foot pedal

The Model 50 Autopen is 34 inches high, 34 inches wide, and 34 inches deep. It weighs 100 pounds and operates on a current of 110 volts, 60 cycles. Among other uses recommended by the Autopen Company is "Autographing Books and Pamphlets."

The machine is priced at $975, with an additional $40 (heavy duty, $60) for a signature recording on a plastic matrix.

Believed to be the invention of R. M. De Shazo and his brother, this model has been in use since about 1958, replacing an earlier model in which the matrix was on the side of the machine.

Matrixes can be interchanged in a few seconds, so that the same machine can sign for many persons. As a security measure, the matrixes are usually locked in a special metal cabinet when not in use.

The robot writing a signature

Photographs by Roy Schatt; posed by Diane Brooks Hamilton

I got an appointment to view the robot and saw it sign letter after letter, each with a perfect signature. Then I asked the operator: "Doesn't the signature pattern on the matrix ever wear out?"

"Oddly, no." The operator lifted the matrix out of the machine. "See how light it is, all plastic. It actually lasts longer than these metal posts between which it passes in activating the pen. When the posts get worn on one side, and the signature tends to level out, we simply turn them around and use the other sides. When both sides are worn, we replace the posts. But we only replace the matrix if it accidentally gets chipped."

"What are these wavy lines in the matrix? It looks like a crudely carved boomerang."

"As the matrix passes through these little metal posts, each curve affects the movement of the pen. And these humps on top of the matrix lift the pen up, so as to separate the first from the last name, or dot an *i*."
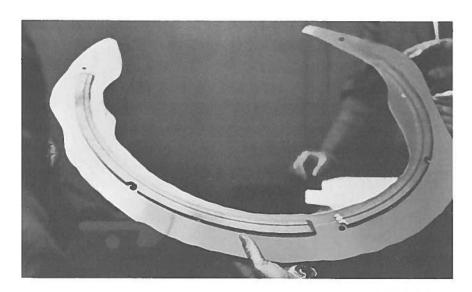
The operator fitted the matrix into the machine on a large flat circular wheel, then pushed the starting switch. He showed how the signature was written as the wheel rotated, passing the matrix between the two posts, with a pause until the matrix completed a full rotation and returned for another signature. "Watch," he said. "I will duplicate the job of the matrix with my hand." He wiggled the two posts, producing a wild scribble on the paper. "If I practised for many years, I might be able to write a word or two."

"Can you use any sort of pen?"

"Yes; right now I'm using an Esterbrook. But even a pencil will sign as well." He took out the Esterbrook and fitted a ball-point pen into the circular metal claw, tightening a screw to secure it. This time the pen signed with a spidery scrawl, with open *o*'s not visible in the Esterbrook signature.

"And if," continued the operator, "I sign with the machine working at top speed, the *o*'s and *e*'s and *a*'s tend to fill with ink. Or if the pen is fastened in the holder too low, there may even be an extra flourish in the signature. Or too high, whole letters may disappear. Definitely this machine has got a mind of its own."
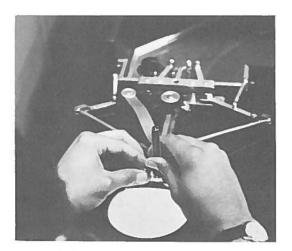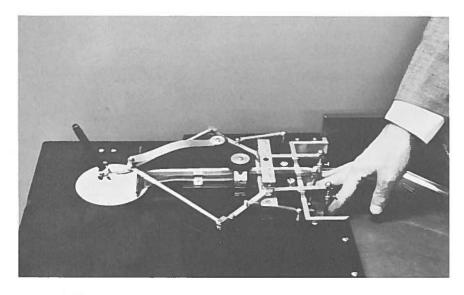
The Robot at Work

Signature recording on a matrix

The matrix adjusted in the machine

Placing a pen in the robot

Operating the mechanism by hand

The President's Aides Get Their Signals Mixed

On June 15, 1961, Kennedy's special assistant, Kenneth O'Donnell, admitted that the President had used a machine to sign his letters during the Presidential campaign. A year and a half later, Kennedy's press secretary, Pierre Salinger, vehemently denied the existence of a robot signer, exclaiming to newsmen:

"Absolutely untrue! There is no such machine!"

Under pressure Salinger later admitted the existence of the automaton but denied that it was ever used in the White House. (See Robot Signature Pattern VI, used while Kennedy was President.)

In his fascinating book, *Congress: The Sapless Branch* (Harper and Row, 1964), Senator Joseph S. Clark of Pennsylvania candidly admits that he dictates and signs very few of the thousands of letters sent out over his signature each year. Form letters are typed on a robotyper, a semi-automatic machine which produces a form letter at the press of a button.

Senator Clark goes on to explain how most of his letters are signed: "There is still another gadget widely used on Capitol Hill . . . My signature is reproduced, or forged if you will, to practically all my letters by a device known as an 'Autopen'—a wonderful product of automation which saves precious hours each week. There are three forged signatures. Most answers get the formal 'Joseph S. Clark.' Politicians who are not intimate get 'Joe Clark.' Friends get 'Joe' as do a fair number who are not friends but call me 'Joe' when they write."

THE WHITE HOUSE
WASHINGTON

June 15, 1961

Dear Dr. Kronovet:

The President has asked me to reply to your letter of April 20th and to apologize for the delay in this response.

During the national campaign the great volume of mail that was received by Senator Kennedy made it impossible for him to personally sign each and every letter. Therefore, much of the routine mail was processed through a machine which duplicated his authentic signature.

With kind regards,

Sincerely,

Kenneth O'Donnell
Kenneth O'Donnell
Special Assistant to the President

Dr. Milton Kronovet
75 Ocean Avenue
Brooklyn 25, New York

Enclosure

Above: Kenneth O'Donnell admits that Kennedy used a signature machine. (June, 1961)

Below: AP News Release in which Pierre Salinger is quoted as saying: ". . . there is no such machine." (December, 1962)

JFK Uses Name-Signing Machine, Says Expert

By Associated Press

NEW YORK.—Is a machine signing letters for President Kennedy? A New York autograph dealer says yes. The White House says no.

A claim that the President's signature is being automated was made today on the NBC-TV "Today" program by Charles Hamilton. He has been an autograph collector for 37 years and a dealer for 10. He recently published a book on collecting signatures and manuscripts.

He said that for the first time in history a machine is being used to sign the President's name to official White House letters.

Hamilton said he saw nothing wrong with using such a device for routine letters, but that there might be grave consequences if used by an unauthorized person with access to White House stationery.

Hamilton said he was not implying that Kennedy used a machine to sign anything important, but that it was used to fill autograph requests and on letters of no great importance. He said he had found examples in which signatures from different letters could be superimposed, with one exactly matching the other. No person ever signs exactly the same way by hand each time, Hamilton said.

'Absolutely Untrue'

In Washington, Press Secretary Salinger said of Hamilton's claim: "Absolutely untrue, there is no such machine."

Salinger said Kennedy's name is duplicated on some of the thousands of photographs sent out in response to requests, but that President Eisenhower did the same thing.

He added that certain routine documents are signed for Kennedy by others who are authorized to do so.

The Famous "Buttonhook" Signature

⋙→

During his campaign for the Presidency Kennedy used a dozen or more form letters, adapted to answer the thousands of inquiries and proffers of support which poured in on him from every section of the country. His robot signed nearly every photograph and form letter. The "buttonhook" signature, which I have so named because the terminal "y" resembles a buttonhook, is by far the most abundant. Judging from the large numbers offered to me every week, many thousands of such form letters bearing this robot scrawl were mailed from his campaign headquarters.

Martin Wagner, a collector who wrote about the "buttonhook" signature to the President's private secretary, Evelyn Lincoln, received the usual "authentication" furnished by the White House.

To fulfill the requirements of the Autopen Company, manufacturer of the robot, Kennedy signed two signatures at the same time on an application form provided by the company. These two signatures, almost identical, are here considered a single robot signature. Examples I-A, I-B, and I-C are exactly the same; yet they differ slightly from examples I-D through I-K.

The authority-to-cut-signature form is illustrated on the same page as Robot Patterns II and III. (See page 15). It is probable that every robot signature exists in two slightly different variations. When to designate a variation as a new pattern has proved a problem. On the opposite page, because the buttonhook machine signature is so common, its two variants are considered as one pattern. But on page 15, to emphasize the fact that these variations exist, and to illustrate the difference more graphically, they are considered as separate patterns, designated Robot Patterns II and III.

THE WHITE HOUSE
WASHINGTON

July 17, 1961

Dear Mr. Wagner:

This will acknowledge your letter of May 22nd.

The signature that you enclosed is the signature of the President. I am sorry that you felt that it was not his signature.

With kind regards.

Sincerely,

Evelyn Lincoln
Personal Secretary to
the President

Mr. Martin Wagner
974 East 99th Street
Brooklyn 36, New York

Sincerely,

John F. Kennedy

I-D (October, 1960)

John F. Kennedy

I-E (December, 1960)

I-F (1960)

I-G (1960)

Sincerely,

John F. Kennedy

I-H (August, 1960)

Sincerely,

John F. Kennedy

I-J (November, 1960)

I-A (owned by Martin Wagner, with authenticating
letter by Mrs. Evelyn Lincoln)

Sincerely,

John F. Kennedy

I-B (October, 1960)

I-C (1960)

I-K (no date)

Deceptive Informal Signature

≫→

Because Kennedy used his nickname, Jack, for Robot Signature Pattern II, many recipients believe he personally signed. It seems incredible that so informal a scrawl should be entrusted to an Autopen! This signature pattern was apparently used in the spring of 1960 and was probably abandoned because the matrixes, as sometimes happens, were accidentally chipped.

Reconstruction of Kennedy Signatures on a Form Provided by the Autopen Company ≫→

The original form, signed by Kennedy and doubtless authorized by him, probably closely resembled this reconstruction, which illustrates the great similarity—yet minute difference—in signatures signed by the future-President at the same time. Because of the huge demand for his signature on letters and documents, Kennedy's robot was constantly at work. For this reason, Kennedy very probably ordered two matrixes at once, one from each signature, perhaps alternating them in use but more likely using one until it chipped, then using the second, almost identical pattern.

A Variant Robot Signature

≫→

Strikingly similar to the preceding pattern, Robot Signature III is certainly from a second master signature written by Kennedy at the same time as the signature for Pattern II.

Robot Signature, Pattern II

Sincerely,

John F. Kennedy

II-A (January, 1960)

Sincerely,

John F. Kennedy

II-B (February, 1960)

Sincerely,

John F. Kennedy

II-C (February, 1960)

First Choice No. 606h _____ (We must have 2 signature samples)   Autopen Model No. 50 _____

Authorization to Cut Signature Recording: Purchase Order No. _____

By _____ or By _____
(Above Individual)   (Dealer or Witness)

MAIL TO   **INTERNATIONAL** *Autopen* **COMPANY**

Signature Division

Reconstruction of Kennedy signatures on Autopen form

Robot Signature, Pattern III

Sincerely,

John F. Kennedy

III-A (April, 1960)

Sincerely,

John F. Kennedy

III-B (May, 1960)

A "Master" Signature Probably Written by an Aide

⇛→

In this robot signature, Pattern IV, every letter is legible, a pedestrian and undistinguished chirography which bears little similarity to Kennedy's own virile hand, except for the feeble effort to imitate his capital "J."

An Early Robot Signature

⇛→

In Robot Signature Pattern V (opposite), Kennedy's script, even in the writing of his last name, is extremely illegible. This signature appears on letters written in 1958 and apparently was not used during the Presidential campaign.

Robot Signature, Pattern IV

Sincerely,

John F. Kennedy

IV-A (July, 1960)

Sincerely,

John F. Kennedy

IV-C (July, 1960)

Sincerely,

John F. Kennedy

IV-E (August, 1960)

Sincerely,

John F. Kennedy

IV-B (July, 1960)

Sincerely,

John F. Kennedy

IV-D (August, 1960)

Sincerely,

John F. Kennedy

IV-F (November, 1960)

Robot Signature, Pattern V

V-A (no date)

V-D (no date)

Sincerely,

John F. Kennedy

V-B (November, 1958)

Sincerely yours,

John F. Kennedy

V-E (July, 1958)

V-C (no date)

The Robot at Work in the White House

⋙→

Since the administration of Chester A. Arthur (1881-85), it has been the custom of most Presidents selectively to distribute engraved views of the White House, personally signed. These two views of the White House, both signed as President, indicate that Kennedy's aides who denied the existence of the robot in the White House were mistaken.

When a sheet of paper is firmly fastened in the machine, the robot-pen will sign scores of signatures, all identical, in exactly the same place, so that they appear to be a single, very heavily penned signature. But from these two examples of a scarce pattern, it is clear that the operator did not firmly secure the White-House cards in the machine before activating the pen. Perhaps the cards were too small to fit conveniently under the securing bar, or perhaps the operator was in a hurry. Thus, although the component parts of each signature superimpose, the two signatures vary slightly because the cards were not held securely during the signing. Notice that, on one signature, the operator allowed the card to slip while the robot was placing the umbrella-like bar on top of the *J* in *John*.

When I watched the machine at work, the operator obligingly showed me how even a mere sigh could affect a signature.
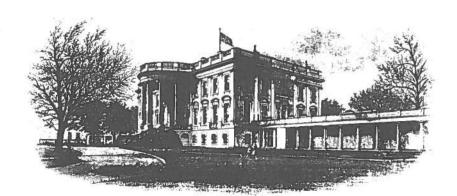
"You see," he observed, "I just drew a deep breath, and it was enough to change the signature. And if I don't secure the letter to be signed before I activate the machine, sometimes the signature is quite different, especially in the loops and curves. Even though I use this metal clamp to hold the paper down, I still have to steady each sheet with my hands."

Robot Signature, Pattern VI
(used as President)

VI-A (no date, but as President)

VI-B (no date, but as President)

2 TO SIGN OR NOT TO SIGN: SOME PROXY SIGNATURES

O DOUBT CAESAR HAD A SECRETARY who wrote and signed letters for him. Machiavelli did. So did other great leaders of the Renaissance. Napoleon's brevets were skillfully signed for him by Hugues Maret. And in modern times the "secretarial forgery" or "proxy signature" is so often used that it meets with universal acceptance. Franklin D. Roosevelt employed seven secretaries who signed his name adroitly; and his private secretary, Missy LeHand, even scrawled a bold *Franklin D. Roosevelt* on his personal checks.

All three of my secretaries imitate my signature with great facility and although I dictate a few of the scores of letters which go out over my signature every week, I sign not more than one or two a month.

However, when someone requests my autograph, I personally sign my name. To do otherwise, in my opinion, would be to perpetrate a fraud.

Obviously the enormous burden imposed by the office of President makes it impossible for the Chief Executive to comply with all the requests for autographs which reach him every day. During his terms of office, Eisenhower responded to autograph requests by sending a facsimile signature on a White-House card, with the word *facsimile* printed on the back. On rare occasions he signed personally as a special favor.

But Kennedy established for the first time in history a policy—I hope not a precedent!—of sending out proxy or robot autographs *not* so identified, and often with letters of authentication from his various aides.

On December 15, 1961 in an Associated Press release

Presidential press secretary Pierre Salinger vehemently denied the existence of a signature machine but added that "on some of the many Kennedy photographs sent out, Kennedy's name is duplicated . . . some routine documents are signed for Kennedy by authorized persons." Apparently the admission that documents were signed for him was disturbing to the President, for Salinger subsequently declared that "the only duplication of the President's signature authorized now is a facsimile (proxy) signature on some photographs of the President."

Adding to the contradictory statements issued by the President's aides, Mrs. Evelyn M. Lincoln, Kennedy's personal secretary, commented to reporters after his death:

"He always wondered why he couldn't sign all the photographs himself. He had no idea how much time it would take."

The public reaction to this candid admission that Kennedy had not personally inscribed his photographs must have jolted Mrs. Lincoln, for on February 19, 1964 in a second press interview, she covered the same subject, changing her story completely: ". . . every morning at about 8 o'clock, when he (Kennedy) got to his office, there was always a stack of photographs, nearly a foot high, for him to autograph.

"He never complained about doing that; he just got right on it, and by 9:30 or so, he would have them done."

If the President actually spent an hour and a half each day —amounting to at least one full day in every week—scribbling his name on photographs, he was certainly neglecting his responsibilities to the country.

However, I am inclined to think that most of the "inscribed" photographs of Kennedy as President will bear the imitations illustrated on the next four pages—those by Secretary I or Secretary II, easily identifiable because there is only a superficial resemblance to Kennedy's own signature.

Possibly executed by Lawrence O'Brien, but more likely by Priscilla Wear, these legal "forgeries" are remarkably consistent, almost as though they were signed by machine. At the top of the page are three authentic signatures of Kennedy as President which are imitated below in the eight examples by Secretary I. Because the proxy signatures end in what appears to be a "w" with a flourish under it, I have labelled the work of Secretary I as the "w" signature. It is extremely common and is found on most souvenir items as President, such as first-day covers, photographs, White-House cards, signed programs, books and similar items. Kennedy's middle initial resembles a capital A or a plus sign. The phrase "with best wishes" is well executed, but a comparison with the same phrase in Kennedy's hand—which may be seen in Chapter IV—reveals many differences.

As usual, many of these signatures bear official authentications. Signature I-D was sent out by Mrs. Lincoln, who wrote: "I am happy to enclose an autographed White-House card which comes with the President's cordial greetings."

Recently I saw a "w" signature accompanied by a letter of Larry O'Brien dated December 17, 1963 (more than three weeks after Kennedy's murder). O'Brien wrote: "Fortunately the late President Kennedy signed your etching before his passing . . ."

A comparison of Larry O'Brien's signature with some of the inscriptions (allegedly in the President's hand) which precede the "w" secretarial imitation shows many points of similarity.

However, an eye-witness to some of the secretarial forgeries told me: "I was a close friend of Priscilla Wear, who worked in the office of the President. I used to watch her practice writing Kennedy's signature by the hour. Once she said to me, 'In heaven's name, don't ever tell anyone you saw me doing this!' Priscilla told me she was authorized to sign Kennedy's name to photographs and souvenir items, but not to White-House letters."

Secretary I

(with three authentic signatures for comparison)

1. (September, 1962)

APPROVED

FEB - 2 1962

2.

3 (October, 1963)

Three official signatures as President, 1962-63

THE WHITE HOUSE
WASHINGTON

I-A

THE WHITE HOUSE
WASHINGTON

I-B

THE WHITE HOUSE
WASHINGTON

I-C

THE WHITE HOUSE
WASHINGTON

I-D

I-E

I-F

I-G

I-H

Imitation by Secretary I, based on the authentic examples illustrated above
(all undated, but 1961-63)

The Comic "Lemming" Signature

⇛→

Perhaps the most amusing attempt to imitate President Kennedy's signature, an attempt which appears even on letters mailed from the White House, is by Secretary II, almost certainly Mrs. Evelyn Lincoln. At the top left is a very early example of Mrs. Lincoln's imitation of Kennedy's signature, so different that it shows no effort to mask her own script. Although the initials *JFK:el* appear next to the complimentary close of the letter, this marks a rare exception, for Kennedy employed many secretaries to sign his name—and they were not necessarily the same secretaries who typed the letters. The secretarial initials at the end of his letters cannot necessarily, therefore, be identified as those of the proxy signer.

Notice that, in example II-E, allegedly an inscription by Kennedy (and authenticated by Mrs. Lincoln) to Cornelius Greenway, the name *Cornelius Greenway* is obviously in the hand of Evelyn Lincoln. Compare the medial *n* in Lincoln with the medial *n* in Cornelius, and the *o* in Lincoln with the *o* in Cornelius, and the *l* in Evelyn with the *l* in Cornelius. A slight improvement in this secretarial fabrication occurs in the phrase "with best wishes," but it is less successful than the imitation of Secretary I.

Because of its amusing similarity to the name given to a certain fatalistic short-haired Arctic rodent, I have designated this inept imitation the "Lemming" signature.

Sincerely yours,

[signature: John Kennedy]

John F. Kennedy

II-A (April, 1956)

Sincerely yours,

[signature: John Kennedy]

John F. Kennedy

II-B (March, 1958)

Sincerely yours,

[signature: John Kennedy]

John F. Kennedy

II-C (January, 1959)

United States Senate
WASHINGTON, D.C.

September 7, 1960

Rev. C. Greenway, D.D.
961 Ocean Avenue
Brooklyn 26, N.Y.

Dear Rev. Greenway:

Shortly before Senator Kennedy left Washington last week he signed the original cartoon which you forwarded to him. He wanted you to know that it was a pleasure for him to do this for you. It is being sent to you under separate cover.

Sincerely,

[signature: Evelyn Lincoln]

Evelyn Lincoln
Secretary to
Senator Kennedy

II-E (transmittal)

[signature: with very best wishes, John Kennedy]

II-D (1959)

[signature: To Cornelius Greenway with very best wishes, John Kennedy]
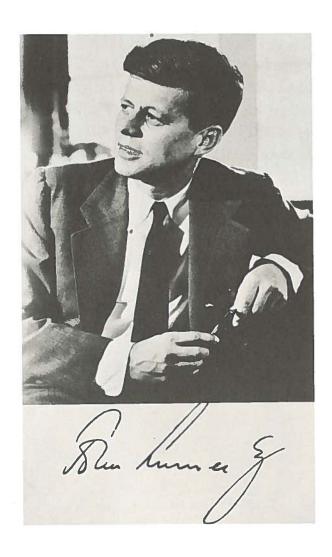
II-E (September, 1960)

Photograph Signed for Kennedy by Secretary II

The "Lemming" signature

(See preceding page)

Photograph Signed for Kennedy by Secretary III

The "stuttering" signature

(See following page)

The Secretarial Signature that "Stutters"

⇉→

The signature of Secretary III (opposite) I call the stuttering signature because of its plainly visible *er*, traditional symbol of speech fumbling.

The *er* signature of Secretary III was apparently used only while Kennedy was in the Senate. The fourteen examples are arranged not chronologically but aesthetically and are set forth to give a composite picture of a secretarial imitation frequently used between 1956 and 1960.

Just as the fabrication of Secretary I is the most common as President, the proxy signature of Secretary III is the most abundant during the senatorial years. Hardly a day passes that some person desperately in need of money does not approach me with the hope of selling a letter signed with one of these proxy signatures. Often I have been asked as much as $5,000 for such a valueless letter. The owners naturally believe that they possess an authentic letter of Kennedy, and if they query the aides of the former President they usually receive a letter of authentication.

Secretary III

Sincerely yours,

John F. Kennedy

III-A (August, 1957)

III-B (no date)

III-C (no date)

Sincerely,

John F. Kennedy

III-D (April, 1959)

III-E (April, 1957)

John F. Kennedy U.S.S.

U. S. GOVERNMENT PRINTING OFFICE   16—15102-2

III-F (February, 1957)

Sincerely yours,

John F. Kennedy

III-G (January, 1957)

Sincerely,

John F. Kennedy

III-H (January, 1959)

Sincerely yours,

John F. Kennedy

III-J (May, 1957)

Sincerely yours,

John F. Kennedy

III-K (September, 1956)

Sincerely yours,

John F. Kennedy

III-L (June, 1960)

Sincerely yours,

John F. Kennedy

III-M (no date)

JOHN F. KENNEDY U.S.S.

U. S. GOVERNMENT PRINTING OFFICE   16—15102-2

III-N (June, 1959).

Sincerely,

John F. Kennedy

III-O (December, 1958)

A Galaxy of Proxy Signatures

➤➤→

The eleven imitations on the opposite page bring to a total of fourteen the known secretarial imitations of Kennedy's signature, but they also suggest that there may be other proxy signers still undiscovered.

Most of these imitations are rather inept, especially IV, VII, and XIII. Number V was signed on a form letter (1952) to insurance agents. Number VI actually resembles Kennedy's signature on good behavior. Example IX, a lithographed signature used on a campaign form letter in 1960, appears to be a tracing of an authentic signature by Kennedy.

Sincerely yours,

John F. Kennedy

John F. Kennedy

IV (August, 1952)

Sincerely,

John Kennedy

John F. Kennedy

V (October, 1952)

John F. Kennedy

VI (no date)

John Kennedy

VII (no date)

To Jim Henry
with best wishes
John Kennedy

VIII (no date)

Yours sincerely,

John Kennedy

United States Senator

IX (1960)

John Kennedy

X (May, 1961)

John Kennedy

XI (about 1960)

John Kennedy

XII (About 1961)

with best regards

John Kennedy

XIII (As President, 1963)

John Kennedy

3 FRANKLY SPEAKING:
THE FRANKING SIGNATURES OF KENNEDY

THE LAST PRESIDENT TO ENJOY the franking privilege was U. S. Grant. On July 1, 1873, during Grant's second administration, Congress passed a law prohibiting the official use of the frank, later restoring it to senators and representatives but not to the President. Curiously, the Vice-President, in his capacity as president of the Senate, is allowed to free-frank his mail. But the President must use either penalty envelopes or regular postage stamps.

Those who seek franking signatures of the Presidents after Grant must usually content themselves with franks signed when the Chief Executive was an army officer (as Hayes and Garfield); or while he was in the Senate or House of Representatives (as Garfield, McKinley, Harding, Truman and L. B. Johnson); or while Vice-President (as Theodore Roosevelt, Coolidge, Truman and L. B. Johnson); or while ex-President (as Hoover and Truman, who were granted the privilege in 1958).

There exist, however, a few "fabricated" Presidential franks signed by special favor—one of Rutherford B. Hayes, two or three of Coolidge and perhaps half a dozen of Franklin D. Roosevelt.

To a collector-friend who asked him for his signature on the upper-right corner of a White-House envelope, F.D.R. replied angrily:

"You're asking me to break the law!"

Later, however, Roosevelt's temper cooled and he obliged his friend.

Like some of our other Presidents, including Kennedy and L. B. Johnson, who collects letters of Sam Houston, Roosevelt was an avid autograph collector. He knew that a "frank," especially by the President, who does not possess the franking privilege, was very valuable to collectors. It could also be used as a weapon in the hands of his political foes as a proof that the President broke the law.

As congressman and senator, Kennedy enjoyed the franking privilege. Much of the mail sent out during his term of office was posted under a printed frank. The original signature from which the cut was made undoubtedly was personally scrawled by the future-President.

Apparently no collector was far-sighted enough to ask Kennedy to frank an envelope with a pen-and-ink signature during the period when he was relatively unknown. And by the time collectors began to besiege him, he was so preoccupied with other and more important tasks that he delegated the autographing job to his secretaries. All of the pen-and-ink franks and souvenir covers which have come to my attention bear proxy signatures.

Of particular interest, both historically and philatelically, is the Presidential "frank" of Kennedy illustrated in this chapter. When it came into my possession I realized that the signature was the usual proxy signature almost invariably found on photographs, White-House cards and souvenir items mailed from the White House. But I was curious to know why the President would permit an illegal frank.

I queried Pierre Salinger, his press secretary, who replied that the envelope was *not* franked! In accordance with White-House policy, Salinger took the opportunity to

"authenticate" the signature, noting also that the cover bore "no official postal cancellation."

This last comment implied that the President had his own cancelling machine; and while I knew that Salinger was in error about the President having personally signed the cover, I was piqued by his comment that it was not officially cancelled. I wrote to the Postmaster of Washington, D. C., enclosing a photostat of the cancellation, and he resolved the matter by replying that it was an authentic cancellation "for philatelic purposes."

An Alleged Presidential Frank

THE WHITE HOUSE

WASHINGTON
AUG
8
9AM
1962
D. C.

VICTOR G. PHANEUF
688 HIGH STREET
HOLYOKE, MASSACHUSETTS

Frank as President, by Secretary I

THE WHITE HOUSE

WASHINGTON

September 12, 1963

Dear Mr. Hamilton:

There is no official postal cancellation on the
photostat you wrote about and the envelope
is not franked. It was autographed by the
President for the collector who requested it and
sent to him inside another envelope.

The President has the same postal obligations
as any other citizen. I cannot understand how
you could possibly construe my letter to indicate
that the President, or anyone else for that
matter, could put a letter into a United States
mailbox and take it back out. I certainly hope
this settles this matter.

Sincerely yours,
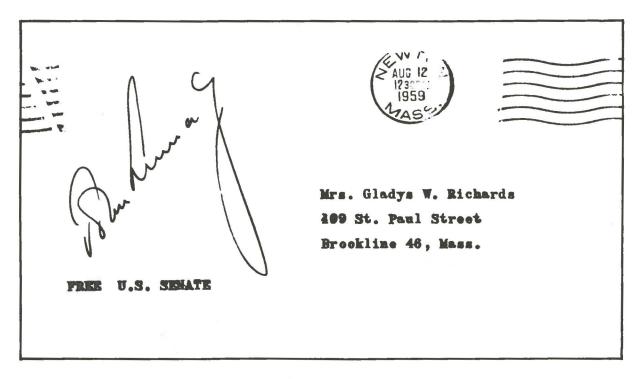
Pierre Salinger
Press Secretary to
the President

Letter of Salinger
commenting on
the alleged frank
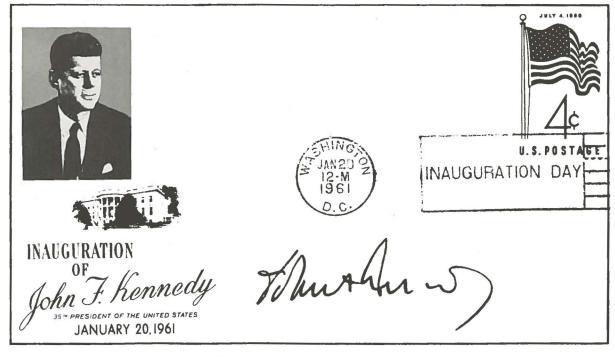
Two Franking Signatures and a Souvenir Cover

Printed frank as Senator

Mrs. Gladys W. Richards
109 St. Paul Street
Brookline 46, Mass.

FREE   U.S. SENATE

Frank as Senator, by Secretary III

INAUGURATION
OF
John F. Kennedy
35TH PRESIDENT OF THE UNITED STATES
JANUARY 20, 1961

Signed Presidential Cover, by Secretary I

4 FROM KENNEDY'S OWN INKWELL: AUTHENTIC SIGNATURES

A JESTING HARVARD STUDENT once offered President Kennedy a free enrollment in a handwriting course!

Certainly Kennedy merits a place in America's Hall of Illegible Chirographers, along with Horace Greeley, of whom a wag once said, "If Belshazzar had seen Greeley's handwriting on the wall, he would have been a good deal more frightened than he was!"

There is a startling parallel between the mutinous scrawls of Kennedy and Napoleon, perhaps history's worst penman. Napoleon thus explained his bad writing to his aide, General Gourgaud:

"My ideas outspeed my pen—then goodbye to the letters and the lines."

Doubtless this was true of Kennedy, whose intellectual keenness and impetuosity are revealed in the speed with which he wrote, his words piling head-long across the page.

Both Napoleon and Kennedy varied their signatures from day to day. But here the chirographic parallel between the two great men ceases. Napoleon used a pen with difficulty, Kennedy with ease. The Man of Destiny was unable to turn out a legible script, even when he labored with the quill; Kennedy could, if he wished, sign his name with impeccable clarity.

As a boy, the future-President wrote a clear, rather undistinguished hand; but his impetuosity was even then evident.

A Plea for a raise
by Jack Kennedy
Dedicated to my
Mr. J. P. Kennedy

Chapter I

My recent allowance is 40¢. This I used for areoplanes and other playthings of childhood but now I am a scout and I put away my childish things. Before I would spend 20¢ of my ¢40 allowance and in five minutes I would have empty pockets and nothing to gain and 20¢ to lose. When I a a scout I have to buy canteens, haversacks, blankets searchligths ponchos things that will last for years and I can always use it while I can use a cholcolate marshmellow sunday with vanilla ice cream and so I put in my plee for a raise of thirty cents for me to buy scout things and pay my own way more around.

Finis

John Fitzgerald Francis
Kennedy

Boyhood Letter, Age about Ten

In this delightful early letter, a "plea for a raise" addressed to his father, cubscout Kennedy reveals an alert mind and an unusual skill in spelling. The boyish handwriting, soon to develop into a rapid-fire scrawl, is very easy to read. A few of the letters, especially the *f*, suggest the writing of his maturity. Notice that he has signed his full name, including the confirmation name Francis, which he later dropped.

Dear Jeff.

I finally got out of the infirmary and the doctor said that I did not have the mumps and the nurse admitted that it was doubtful if I had the disease that you referred. I heard that you had 116 girls at the dance. Choate had 135 and Choate has 6 forms and none of the lower forms brought any. We won't play you in baseball till next year. We had a trackmeet yesterday and three school records were broken. The captain ran the hundred in 9⅗ but it was not counted as official because the wind was with him. We had Dr. Seykelly and Mr. Hyde last night. It was pretty good and they had a

Letter from *The Choate School*, Age about Fifteen
(First Page)

A fascinating epistle to his friend Jeffrey Roche, then at Lawrenceville. Notice that in the

good bedroom scene. School get out the eigth if you go Plan B or don't take Colledge Board and then I'm going down to Cape Cod. The other nights a member of the Studen Council got me out on the track and had me running a mile & ¼ straight. He had some kind of a wire coat hanger and every time I slowed up he would ∞ smack me of on the tail. He was a track man and he went as fast as hell. I was so dammed pooped that I could hardly walk the next day. It was at 11 at night. If you want to write Quigly write her care of American Express

Smittily yours

Jack Kennedy

Writer

The Development
of Kennedy's Signature
from Schoolboy to President

John F Kennedy
French E

Mr. Procter

Student at Choate School (1934)

PRINT ALL PROPER
NAMES PLAINLY   CLASS OF 1940
LEGAL NAME
IN FULL   *Kennedy*   ,   *John*   *Fitzgerald*
(Do not use initials)   (Last name)   (First name)   (Middle name or names)
Home address in full   *294 Pondfield Rd.*
    Bronxville   New York
Date of birth *May 29 1917*   Place of birth   *Brookline*
Is your father living? *Yes*   Is your mother living? *Yes*
If your parents are separated, please so state
Father's full name, whether living or dead   *Joseph Patrick Kennedy*
Give his address   *30 Rockefeller Plaza*
    His business or profession   *Banker*
Mother's full name before marriage   *Rose Fitzgerald*
    Her present address   *294 Pondfield Rd - Bronxville - N.Y.*
Date of your admission to Harvard College   *June 1935*
School from which you were admitted to Harvard College   *The Choate School*
    Address of School   *Wallingford - Conn.*
Name, address, and relationship of person to whom communications should be sent concerning your
    college work   *Mr. Joseph P. Kennedy - Parent*
    30 Rockefeller Plaza - N.Y. City - N.Y.

SEE OVER

Personnel card, admission to Harvard

Jack Kennedy

As Author of "Why England Slept" (August, 1940)

*John F. Kennedy
Lt. (jg) USNR.*

As ex-Commander of P.T. 109 (October, 1943)

John Kennedy

As Congressman (1952)

John Kennedy

As Senator (1960)

John F Kennedy

As President (1962)

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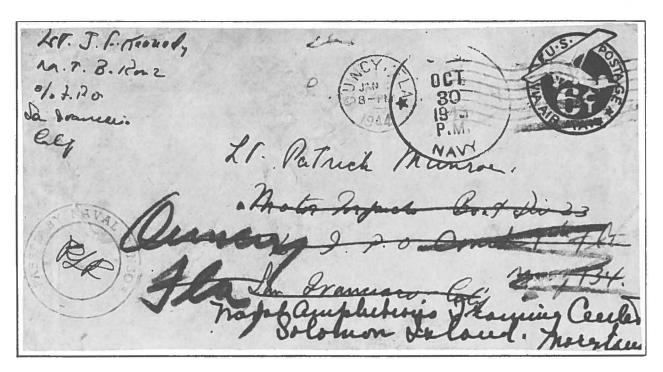
In the first example (previous page) penned at Choate School in 1934, notice that Kennedy has signed his name with the bold egotism of youth; but when he wrote the Roman numeral IV he scrawled it so rapidly that the pen did not leave the page while making the top and bottom crossbars.

It is amusing to note that in his application for registration to Harvard (previous page) Kennedy misspelled the name of the man who was to be one of his leading political foes, Rockefeller. The error was corrected by a clerk in the registrar's office.

As an officer in the Navy Kennedy developed the swift, almost tumultuous script which characterizes his later writing; but the words at this earlier period were more legible and the signature could easily be deciphered.

Cover Addressed and Signed as Lieutenant
(October, 1943)

"Let's Flip a Coin!"

These four words decided whether Lieutenant Patrick Munroe, commander of P-T Boat 110, or Lieutenant John F. Kennedy, commander of P-T Boat 109, would take the dangerous assignment in New Guinea waters. Both were eager for the hazardous mission.

Lieutenant Kennedy won the toss.

After his vessel was rammed and sunk (later Lieutenant Munroe also lost his boat), Kennedy wrote to his comrade (the last page of his letter is pictured on the next page), noting of his exploit:

"We were extremely lucky throughout."

And he ended his letter, one of the few extant from this early period, with the traditional:

"Over & out, Jack."

That's about all the other Pat,
except that strangely enough Kelly is the
big popular figure these days - having done an
extremely good job - and putting himself out
in front plenty.

Thanks for your good wishes on
our rescue. We were extremely lucky
throughout. After to-day it won't happen
again. Working out Jacobsen's base - & went
in to see the doc about some coral
infections I got. He asked me how I got
them - I said swimming - then
the burst loose with - "Kennedy - you
know swimming is forbidden in ~~this~~
~~~~~~ this area - stay out of the
god-damned water." So now to an official
order - so no more skiting. Best regards
to Sted - Red - and all the boys - Remember
me to Mac if you see him

Yours ever

Jack.

By the time he entered Congress the future-President had evolved the eccentricities of penmanship which make his constantly varying signature the most amazing and perplexing of any in American history. The five signatures reproduced here, all signed within a period of five months in 1953, illustrate the lack of consistency in his writing. Yet there is a striking similarity between them—a similarity which was to vanish during the years in which Kennedy was moving toward the Presidency.

Sincerely yours,

John F. Kennedy

Sincerely yours,

John F. Kennedy

Sincerely yours,

John F. Kennedy

Sincerely yours,

John F. Kennedy

Sincerely yours,

John F. Kennedy

As Congressman
Authentic Signatures (February to June, 1953)
After 1953, Kennedy signed
very few letters personally

Sincerely yours,

John F. Kennedy

John F. Kennedy

(October, 1950)

John Kennedy

(1952)

Sincerely yours,

John Kennedy

(June, 1952)

Sincerely,

John Kennedy

John F. Kennedy

Mary Mary Kennedy Lincoln

(November, 1952)

Sincerely yours,

John Kennedy

John F. Kennedy

(no date)

With the highest
regards and esteem
of his friend —

[signature]

(January, 1958)

John:

Would you care to
have lunch on
Wednesday — Senate
Restaurant 1:15 —

J. K.

(January, 1958)

[signature]
U. S. Senator
(no date)

[signature]
(1960)

[signature]
(no date)

From the Desk of
HON. JOHN F. KENNEDY

[signature]

(no date)

United States Senate
WASHINGTON, D. C.

Dear Andy,

Congratulations! I don't know how you do it. Running in one of the most ardent political cities in the country — for two in every year. I find the prospect

Inscription of Kennedy in a copy
of "Profiles In Courage"

Inscription of Kennedy in a copy
of "As We Remember Joe"

Kennedy Signing a Copy of
As We Remember Joe *for John Bond,*
(The inscription is
reproduced on the preceding page.)

By 1954 Kennedy had almost ceased to sign his personal mail, delegating the task to various secretaries. And just as they took from the ambitious young senator the burden of scribbling his name, so they were in large measure to be relieved a few years later by the robot which adroitly reproduced Kennedy's personal scrawl.

The authentic signatures of Kennedy from 1954 until his murder in 1963 represent a decade in which his signature varied so greatly from day to day, even from hour to hour, according to the circumstances under which he was writing, that it is sometimes difficult even for an expert to authenticate them.

Yet despite their many differences, the signatures of Kennedy have one thing in common—they *vary!* The hasty scrawl of the President on a banquet program for one of

Signature signed at a banquet, 1960

several hundred guests who have lined up for his autograph might not be so legible as the signature set to an important document in the quiet of his study earlier in the same day; but this very lack of consistency sets the genuine signatures apart from the proxy and machine signatures!

Above all, one detects in the authentic signatures a feeling of urgency, almost as though Kennedy sensed that the important work must be got out fast, before time ran out. A mere pen lashing at the bottom of a letter sufficed him. He had signed it—that was enough! What did it matter if a few letters were added or subtracted from his signature? What difference if he blotted, or signed *Jack* instead of *John*?

It was, after all—however he wrote it or spelled it—a signature which will never be forgotten.

Informal Notes on Dictated Letters

Sincerely yours,

[signature: John F. Kennedy]

John F. Kennedy

Sincerely,

[handwritten note]

JFK:jd

Sincerely,

[handwritten notes]

Kennedy often jotted postscripts on letters to friends. *Above, left*: April 20, 1962 (as President), to Mrs. Emily Chamberlain of New York; *above, right*: July 13, 1956, to the Associate Editor of the American Weekly; *below*: November 29, 1959, to Andrew P. Quigley.

Kennedy introducing Adlai E. Stevenson, with the nomination written out and signed, about 1957

I would be glad to hear from you on any matter at any time.

John Kennedy

(February, 1961)

(1960)

Sincerely,

John F. Kennedy

(December, 1960)

(1960)

As President

J.F.K.

(no date)

Approved
October 24th 1963
the White House
Washington - District of Columbia
United States of America
John Fitzgerald Kennedy 11:35 AM

(October, 1963)

(no date)

(October, 1961)

Approved:
John F. Kennedy
March 1961

(1962)

(October, 1963)

(March, 1961)

Sincerely,

THE WHITE HOUSE
WASHINGTON

With the best wishes
John F. Kennedy

(May, 1963)

(no date; official facsimile)

THE WHITE HOUSE
WASHINGTON

Sept 15/61

Dear Terry:

I want to
express my thanks to
you for your work on
the crime bills. It was a
fine job.

Sincerely,
Kennedy

Holograph Letter of Kennedy as President

57

5 A POSTSCRIPT ON JACQUELINE KENNEDY

HERE IS IN JACQUELINE BOUVIER KENNEDY'S graceful script all the refinement and beauty one might expect from the writing of a distinguished lady. The legible, print-like letters, formed rapidly yet with delicacy, reflect impeccable taste and originality. In some ways her handsome, cursive hand recalls, without actually resembling, that of Queen Elizabeth, whose writing master, Roger Ascham, schooled his pupil in the beautiful Italic script of the Renaissance.

Unlike many important personalities, Mrs. Kennedy has put warmth and personality into her correspondence. Until her husband became a candidate for President she continued to indite letters in her striking chirography. When at last she yielded to the enormous demands of her position, she followed Kennedy's policy and authorized a secretary to sign photographs and letters for her.

Among the fascinating letters of Mrs. Kennedy which have come my way was the letter to Ronald C. Munro of England, who had asked her for $20,000. Her four-page reply, a tender and moving epistle, fetched $3,000 at auction—the highest sum ever paid at public sale for a letter of a living person.

The last paragraph of this famous letter is reproduced here, together with a secretarial signature which often appears on letters and photographs after 1958.

In the authentic script of Mrs. Kennedy, notice that the *n's* in the signature look like *r's*. The proxy signature is much more legible and lacks the spontaneity and grace of its model.

Conclusion of a Holograph
Letter by Jacqueline Kennedy

I pray that things will work
out for you - as I said - I would have
helped you if I could - I hate to put
an end to your Dream - but I think you
were hoping for a miracle that just wont
happen in the twentieth century -
   May you and your family stay as happy
as you are with each other - and I am sure
God will be kind to you
             Very Sincerely
             Jacqueline Kennedy

With best wishes
Jacqueline Kennedy

Inscription and Signature
Signed for Mrs. Kennedy
by a Secretary

EPILOGUE

ALTHOUGH THE ROBOT WHICH SERVED KENNEDY so faithfully quickly switched its allegiance to another member of the Kennedy family, there is one secretary (Secretary XIII) who for reasons unknown and for an employer unidentified continues to sign the martyred President's name even a year after his death. Since this volume was completed, I have encountered at least half a dozen signatures like the one illustrated here, all with very similar letters of explanation from former aides of Kennedy.

Evelyn Lincoln

November 17, 1964

Dear Mr. Burgdorf:

In cataloging the late President Kennedy's papers, I have just discovered your letter and its enclosures and am delighted to find that they were signed -- apparently only a few days before his tragic passing. I am deeply sorry that this could not come to you earlier.

Sincerely,

Evelyn Lincoln

Evelyn Lincoln

Posthumous signature of Kennedy by Secretary XIII, with letter of transmittal by Evelyn Lincoln

Mr. Karl Burgdorf
Postlagernd/Dompost
Hildesheim
Germany

Enclosures

Karl Burgdorf
Hildesheim
Butterborn 68

A FEW WORDS OF THANKS

O ALL THE DEALERS, HISTORIANS, AND COLLECTORS who so enthusiastically participated in this venture, I should like to express my deepest thanks. No enterprise ever received more cordial aid!

First I should like to record my gratitude to the colleagues who generously allowed me the use of their files. Among these are the distinguished experts, Mary A. Benjamin of New York and Paul C. Richards of Brookline, both of whom gave liberally of their time and ideas, and even volunteered to read the manuscript (which would surely have been much better for their comments, had not time and the printer stood in the way); Dr. Milton Kronovet of Brooklyn, a pioneer in the study of Kennedy's signature, who allowed me to reproduce, not just autographs from his collection, but even an important letter of Kenneth O'Donnell written to him; and Robert K. Black of Upper Montclair, New Jersey, who without reservation placed at my disposal every autograph of Kennedy that came his way.

Few authors have enjoyed such cooperation as was offered me by the outstanding collectors of Kennedyana. Dr. Bernard Pacella permitted me to reproduce several valuable items, including an excessively rare holograph of Kennedy as President; Andrew P. Quigley was no less generous, offering whatever I wished to use from his splendid personal collection of authentic letters; and Patrick Munroe, close friend of Kennedy during World War II, allowed me to publish in facsimile the envelope and last page of an unique letter written to him in 1943 by the future-President.

Jeffrey Roche, of New York, close boyhood friend of Kennedy, generously allowed me to print in full a remarkable letter written to him in 1932; and Roger Butterfield,

also of New York, kindly brought to my attention a significant passage about the Autopen by Senator Joseph S. Clark.

I am grateful to Mrs. John F. Kennedy who graciously permitted me to reproduce the very touching early letter of Kennedy to his father.

Others who furnished facsimiles were Clifford Barrett, Kayo Roy, H. Keith Thompson, and Martin Wagner, who also granted me permission to reproduce a letter to him from Mrs. Evelyn Lincoln.

Especially I should like to thank Henry A. Wihnyk, who put in much time and effort in the hope of clearing up some of the mysteries surrounding Kennedy's signature, and who cheerfully allowed me the use of his personal collection; and my friend, the Reverend Cornelius Greenway, pastor of the All Souls Church in Brooklyn, who placed at my disposal, without reservations or conditions, his enormous collection of signed photographs of Kennedy, certainly the finest and most important in existence.

Of great help was the information furnished by Justin G. Turner of Los Angeles, who telephoned me twice from Washington, D. C. to give me details about the Autopen used by Kennedy; and David C. Mearns, Manuscript Librarian of Congress, who furnished valuable leads for uncovering data about Kennedy's robot.

Particularly I should like to set down my thanks to the libraries which so generously helped: Harvard University, The National Archives, and the Library of Congress. What historical book could ever be finished without their aid?

My debt to H. Keith Thompson, who labored incessantly to put into print a most recalcitrant manuscript, exceeds even that of an author to a helpful publisher.

Finally (and the last shall be first!) I should like to express my deepest gratitude to my wife, Diane Brooks Hamilton, who worked tirelessly with me, night after night, to put together the jigsaw puzzle of Kennedy's handwriting. Although this book is dedicated to her, it might be even more appropriate to call her the co-author.

Index

Robot Signature, Pattern VII
(a recent discovery)

Sincerely,

John F. Kennedy

VII-A (June 25, 1959)

Sincerely yours,

John F. Kennedy

VII-B (July 9, 1959)

Based upon an authentic example furnished by Kennedy, this automated signature is so adroitly scrawled that it can be identified as a machine product only when compared with another signature of the same robot pattern. It was discovered by the author after this volume was printed and suggests that there are other machine and secretarial signatures which remain to be identified.

Nearly every week brings fresh confirmation of the preliminary data presented in this book. At press time, for instance, only two examples of Robot Signature Number VI were known; but since then more than a dozen additional examples have come to light.

If I have made mistakes and omissions in this pioneer probe, I hope that my efforts will nevertheless make the task of identifying these robot signatures easier for future scholars and historians. Little is known yet about the transfer of man's functions to the oiled gears of a machine, and no doubt a hundred years from now what I have written will seem naive. Perhaps the identity of mankind will then be submerged in new and even more frightening mechanisms.

SEVEN ROBOT SIGNATURES

To see the similarities and differences in each of the robot signatures used by Kennedy, place each signature over the examples of the same pattern.

Pattern I-A

Pattern IV

Pattern I-D

Pattern V

Pattern II

Pattern VI

Pattern III

Pattern VII

SEVEN ROBOT SIGNATURES

To see the similarities and differences in each of the robot signatures used by Kennedy, place each signature over the examples of the same pattern.

Pattern I-A

Pattern I-D

Pattern II

Pattern III

Pattern IV

Pattern V

Pattern VI

Pattern VII

Antique Myth, Early Modern Mechanism: The Secret History of Spenser's Iron Man

McCulloch, Lynsey

CHAPTER 4

Antique Myth, Early Modern Mechanism:
The Secret History of Spenser's Iron Man

Lynsey McCulloch

> Immouable, resistlesse, without end.
> (Edmund Spenser, *The Faerie Queene,* V.i.12)[1]

Talus (or Talos), Artegall's "yron groome" (V.iv.3) in Book V of Edmund

Spenser's *The Faerie Queene* and the brazen automaton of Greek myth, appears in both the

classical and Renaissance periods as a striking composite of man and machine, humanoid

in appearance but also the product of *technē* and emergent metallurgic and mechanistic

industries. In modern parlance, Talus is a cybernetic organism or cyborg. Acting as page to

Sir Artegall, Spenser's Knight of Justice, the early modern iron man administers the law,

his hardened frame a tireless tool of the state, his threshing flail the robotic arm of

Spenser's iron and stone-age body politics. Scholarly appraisals of Spenser's Talus have

focused variously on the socio-political and colonial implications of this automated

servant. Does he represent the failure of military NeoStoicism, the advance of Western

industrial development, or the judicial fantasy of Ireland's beleaguered English colonists?

This chapter posits an alternative reading, one that looks to uncover the sensitive

side of this much-maligned figure and to situate him—not only within that familiar nexus

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[1] Edmund Spenser, *The Fairie Queene*, ed. Thomas P. Roche, Jr. (London: Penguin, 1978). All further

references to the text are to this edition.

of retributive justice, military arms and mechanical industry—but also within a context of ancient fable and mythic wonder, tracing his literary journey from the classical accounts of Hesiod, Apollodorus, and Apollonius of Rhodes, in which he communes with the talismanic automata so prevalent in that period, to the Renaissance appropriation of Spenser. This approach will account for the aspects of Talus' personality so often overlooked by critics focused on the iron man as a "terrible creature"[2] or "figure of horror,"[3] namely his physical grace, mediatory role, capacity for unveiling hidden knowledge, and storytelling function. With a particular focus on Talus' interaction with the analogously manufactured figures of Book V—including the armored knights, bionic women, holographic images, and living statuary of Spenser's imagination—this chapter will consider Talus' ontological perversity, his position as both subhuman and superhuman, war-machine and wondrous spectacle. How far can we synthesize these converse categories within the body of a single man/machine and what might such a synthesis portend? In acknowledging Talus' status, not simply as killing machine, but as

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[2] Jane Aptekar, *Icons of Justice: Iconography & Thematic Imagery in Book V of* The Fairie Queene (New York: Columbia University Press, 1969) 41.

[3] Jonathan Sawday, "'Forms Such as Never Were in Nature': the Renaissance Cyborg," *At the Borders of the Human: Beasts, Bodies and Natural Philosophy in the Early Modern Period*, ed. Erica Fudge, Ruth Gilbert and Susan Wiseman (Basingstoke: Macmillan, 1999) 190. Sawday usefully acknowledges in this essay the strained position of the automaton between the worlds of magic and mechanics, but sets Talus squarely within the context of the latter. For a further discussion of Renaissance technology, and Talus' place within it, see also Sawday's *Engines of the Imagination: Renaissance Culture and the Rise of the Machine* (London: Routledge, 2007).

animated statue, and fully considering his relations with the variety of automata represented in antique and early modern texts, this chapter looks to reinscribe the Spenserian rationale behind this most curious of creations. It will also examine Spenser's own identification with the automatous, both as colonist in the contested territory of Ireland and as poet, assessing the extent to which Talus functions as a representation of political instrumentality but also, given his narrative role, as a sign of authorial identity and ambiguity.

Mechanism

Given Spenser's allegorical mode, it is no surprise that scholars have long identified Book V of *The Fairie Queene* as a coded representation of the poet's Irish experiences. Spenser served as secretary to the Lord Deputy of Ireland, Arthur Grey, from 1580 until his employer's ignominious recall to London in 1584 by Elizabeth I, amid rumors of cruelty and bloody excess against the rebels and the indigenous population. If accepted as the companion piece to Spenser's contemporaneous account of Irish politics, his *View of the Present State of Ireland*, Book V reads both as a reflection on the singularity of a military engagement in Ireland, one that requires a strong arm and an understanding of guerrilla warfare, and a troubled apologia for Lord Grey. In this context, Artegall functions as a clear analogue of Grey and Talus becomes inevitably the military arm of the English incursion or, to quote Jonathan Sawday, "the Law as Spenser imagined it should be exercised by the Elizabethan imperium at the expense of Ireland."[4] Several of Book V's major malefactors are imaged by Spenser as Irish, the monstrous Grantorto

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[4] Sawday 190.

amongst them. Grantorto is dispatched by Artegall but Talus is also regularly called upon to pursue and punish the "Irish" rebels within the text. Spenser's retributive fantasy would no doubt have found a strong supporter in Lord Grey de Wilton, but Elizabeth I, in her dealings with Ireland, was wary of appearing the tyrant even by proxy. John Milton, bemoaning another English monarch's reluctance to crush the Irish, certainly envisages Talus as a necessary brute, citing his independence from the strictures of rule and law as his most valuable quality:

> If there were a man of iron, such as *Talus*, by our Poet *Spencer*, is fain'd to be the page of Justice, who with his iron flaile could doe all this, and expeditiously, without those deceitfull formes and circumstances of Law, worse then ceremonies in Religion; I say God send it don, whether by one *Talus*, or by a thousand.[5]

Milton's position may now be politically untenable, but the burgeoning archipelagic scholarship of recent years—while rightfully acknowledging the suffering of a subject state like Ireland—has nevertheless compounded earlier critical treatments of Spenser's "transparent allegory"[6] of colonialism, and once more consigned Talus to the role of guilty imperial pleasure. Richard McCabe is not alone in discerning a deep-felt anxiety in *The*

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[5] John Milton, *Complete Prose Works of John Milton*, ed. Don M. Wolfe et al., vol. III (New Haven: Yale University Press, 1953-1982) 390.

[6] M. M. Gray, "The Influence of Spenser's Irish Experiences on *The Fairie Queene*," *The Review of English Studies* 6.24 (1930): 417.

Fairie Queene with the iron man as the poem's dark centre: "Spenser's poetics interrogate his politics so profoundly as to discover the heart of darkness at the centre of the colonial enterprise."[7]

Scholars have also been alert to Talus' place in the history of Western industrial development, and specifically the application of technology to a military and judicial context. Alastair Fowler has described how "Talus' inhuman, robotic aspects seem to reflect the increasingly technological character of law enforcement and war in the modern state."[8] More recently, Jessica Wolfe has examined the political instrumentalism of the Renaissance period and the misguided courtly emulation, by the Earl of Essex and others, of a Stoical *apatheia.* Holding Talus up as the "perverse, inhuman mascot of Elizabethan military humanism and its devastating array of newfangled machines and strategies,"[9] Wolfe foregrounds Talus' function as a warning against the dehumanizing effects of Stoicism, the concomitant rages that result from such an emotional repression, and the dangers of fashioning human beings as tools.

Myth

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[7] Richard A. McCabe, *Spenser's Monstrous Regiment: Elizabethan Ireland and the Poetics of Difference* (Oxford: Oxford University Press, 2002) 4. For further evaluations of Spenser's colonial conscience, see Willy Maley, *Salvaging Spenser: Colonialism, Culture and Identity* (Basingstoke: Macmillan, 1997); Andrew Hadfield, *Edmund Spenser's Irish Experience: Wilde Fruit and Salvage Soyl* (Oxford: Clarendon Press, 1997).

[8] Alastair Fowler, "Spenser and War," *War, Literature and the Arts in Sixteenth-Century Europe*, ed. J. R. Mulryne and Margaret Shewring (Basingstoke: Macmillan, 1989) 160.

[9] Wolfe 207.

The instrumentality of Spenser's Talus has, in fact, a classically sanctioned legitimacy. Several ancient Greek sources suggest that the brazen man known as Talos or Talon was built in bronze by Hephaestus, the smith-god, and gifted to King Minos of Crete. Others advance a rather different provenance. Talos' origins are certainly confused, not least in Spenser's own mythos, and Hesiod's *Work and Days* proffers another possible derivation:

> And Zeus the father made a race of bronze,
>
> Sprung from the ash tree, worse than the silver race,
>
> But strange and full of power. And they loved
>
> The Groans and violence of war; they ate
>
> No bread; their hearts were flinty-hard; they were
>
> Terrible men; their strength was great, their arms
>
> And shoulders and their limbs invincible.[10]

Spenser too, in elegiac mode, tenders a chronology in which Talus may be inserted: "For from the golden age, that first was named, / It's now at earst become a stonie one" (V.Proem.2). But while Hesiod emphasizes the invulnerability of his brazen figures—brazen in this instance by virtue of their accoutrements rather than their bodies—he also credits the siring of this warlike race to Zeus. It is this divine inception that complicates our perception of Talos and his ilk. The brazen man of Hesiod's *Work and Days* betrays

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[10] Hesiod, *Theogony, Work and Days*, trans. Dorothea Wender (Harmondsworth: Penguin, 1973) 63.

superhuman origins and yet lives a life of stultifying regularity and subhuman mechanization; he patrols Crete on behalf of King Minos, circumnavigating the island thrice daily and attacking with stones any who attempt to alight on shore. Plato's *Minos* and Apollonius of Rhodes' *Argonautica* offer similar pictures of a legal and juridical instrument. In Plato's rationalized version of the tale, a non-brazen Talos traverses Crete displaying the island's laws engraved in brass. The *Argonautica*, unlike *Minos* and Hesiod's *Work and Days*, offers an actual man of brass, the Talos who attacks Jason and the Argonauts and is ultimately destroyed by Medea.

Spenser's Talus, like his classical ancestors, is deftly situated between a sub- and superhuman status. Despite his apparently prosaic employment by the Knight of Justice, this iron man retains a noble history. Astraea, the classical personification of justice, leaving the earth for the last time, bequeaths her groom, Talus, to Artegall. Talus' servility is not in question. But his background as Astraea's personal aid and possible genesis as one of a divinely produced race hint at a magical or deified aspect to his character, one that crucially adapts his nominal status as a mechanical tool. Indeed, *The Fairie Queene* is full of instances in which technology and the supernatural cooperate. Arthur's enchanted shield, invested with magical powers by Merlin, was also manufactured in a more conventional fashion: "It framed was, one massie entire mould, / Hewen out of Adamant rocke with engines keene" (I.vii.33). Book V in particular examines the relationship between sub- and superhuman behaviors. Hercules, who "monstrous tyrants with his club subdewed" (V.i.2), is referenced more than once and the legitimation of his violent tendencies—"with kingly powre endewed" (V.i.2)—raises some interesting questions.

Historically, this laboring demi-god, fathered by Zeus and demonstrating superhuman strength, becomes, at moments of dramatic reversal, a labored subhuman, a muscle-bound fetcher and carrier. [11] More-than-human and less-than-human hereby coexist. This radical confluence is perceptible too in the work of Spenser's contemporaries and the early modern period's wider concern with the vexed interface of art and nature, mechanics and magic.

The iron man has a supporting and prosthetic responsibility: "powre is the right hand of Iustice truely hight" (V.iv.1). But although Talus serves Artegall in this respect, the Knight of Justice is also implicated in the elision of sub- and superhuman; as Astraea's deputy on earth, Artegall is an "instrument" (V.Proem.11) himself. Several accounts of the knight in action stress the mechanical nature of his martial force. In his confrontation with

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[11] William Shakespeare, in his Roman plays, examines labor politics, instrumentality, and the world of the rude mechanical, his definition of "mechanical" crucially extended to include the rulers and senators as well as the plebeian populace. Shakespeare's own "Herculean Roman" (*Antony and Cleopatra*, I.iii.84), the soldier and triumvir Antony, encapsulates the elision of such binary opposites. In *Julius Caesar,* despite his military prowess and political importance, Antony acts primarily as Caesar's surrogate, fulfilling his physical obligations: "Antony is but a limb of Caesar" (II.i.165). In *Antony and Cleopatra,* he becomes once again the right hand of a Caesar, Octavius Caesar. While Cleopatra derides the Roman mechanicals with their "greasy aprons, rules, and hammers" (V.ii.206), her partner, with heavy irony, appropriates the workaday language of the plebeian carpenter or stonemason: "Read not my blemishes in the world's report. / I have not kept my square, but that to come / Shall all be done by the" rule" (II.iii.5-7). Antony functions as a military instrument or bionic appendage operated by others, not unlike Spenser's Talus. See William Shakespeare, *The Complete Works*, ed. Stanley Wells and Gary Taylor (Oxford: Clarendon Press, 1988).

the Amazon Radigund, Spenser imagines him as a blacksmith, striking his foe with

mundane regularity, and the description of his tool inevitably recalls Talus' own weapon,

the iron flail:

> Like as a Smith that to his cunning feat
>
> The stubborne mettall seeketh to subdew,
>
> Soone as he feeles it mollifide with heat,
>
> With his great yron fledge doth strongly on it beat. (V.v.7)

The iron flail, Talus' signature weapon, consisting of a wooden staff at the end of which a

shorter pole or club swings freely, was an instrument for threshing corn by hand and, as

Spenser notes, a "strange weapon, never wont in warre" (V.iv.44). There is no question

that Talus betrays the taint of the laboring classes; he is as much agricultural worker as

military mechanism and his tool suggests as much. But strengthened with iron in this case,

Talus' attribute becomes a rather more threatening prospect. Jane Aptekar, tracing

Spenser's iconography, notes that the iron man shares his attribute with the classical god of

war, Mars.[12] Once again, Talus' ontological status becomes problematic. Is he a god or a

golem?

Master and Servant

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[12] Aptekar, Jane. *Icons of Justice: Iconography and Thematic Imagery in Book V of* The Fairie Queene (New

York: Columbia UP, 1969) 45.

Many of the scholarly arguments representing Talus as a monstrous figure, one extemporizing man's uneasy association with the machine, are predicated on his differentiation from Artegall as the Knight and true champion of Justice and the increasingly fractious relationship that is thought to develop between master and man in the light of Talus' increasing aggression. Kenneth Gross, considering again the Irish analogy, suggests that, "Spenser may choose to hold apart the image of effective violence against rebellion in the person of Talus from the idealistic justification of violence personified by Arthegall."[13] Artegall's own instrumentality confuses the issue and Spenser takes pains to elide the two figures, not, I think, in order to interrogate the mechanistic threat to Artegall's own humanity[14] but rather to foreground the pair's cooperative effort and ultimate commonality. Early descriptions in Book V of the "awfull sight" of Artegall's "wreakfull hand" (V.i.8) undermine any suggestion that the Knight of Justice keeps his hands clean while displacing guilt onto his iron page. It is true that Artegall entrusts Talus with tasks he is not prepared to undertake himself, but several of his delegations credit Talus with more quality than most critics are prepared to do.

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[13] Kenneth Gross, *Spenserian Poetics: Idolatry, Iconoclasm, and Magic* (Ithaca: Cornell University Press, 1985) 89.

[14] Germane here is Jessica Wolfe's characterization of Artegall and Talus according to the medieval philosophy of the king's two bodies, with Artegall as the organic body natural and Talus as the insensate body politic, and her argument that the pair periodically swap roles to indicate the "antithetical qualities demanded by the militaristic ethos of late Elizabethan culture." See Wolfe's *Humanism, Machinery, and Renaissance Literature* (Cambridge: Cambridge University Press, 2004) 203-235.

James Nohrnberg, in his 1976 work *The Analogy of* The Fairie Queene,
acknowledges Talus' communion with classical and medieval automata including his
direct literary predecessor, Talos, the apprenticed nephew of Daedalus.[15] This version of
the myth, in which Talos as inventor produces a saw copied in iron from the backbone of a
fish (a fitting mixture of artificial and organic elements), appears in Apollodorus' *Library*.
Nohrnberg is alert to the gift for invention shared by Spenser's Talus and his ancient Greek
counterpart; unable to enter Pollente's castle in canto ii, Artegall calls on Talus to devise a
method of entry; he 'bad his seruant *Talus* to inuent / Which way he enter might, without
endangerment' (V.ii.20). However, Nohrnberg argues that both stories set the dangerous
autonomy of the servant against the fitting authority and oppression of the master. In
Apollodorus, Daedalus rewards his nephew's precocity by throwing him off a cliff.[16] In
The Fairie Queene, Artegall on three occasions halts Talus' assaults on his enemies, citing
clemency but also expediency and politic reserve as his reasons. In all three cases, and in a
similar scenario with Britomart, Talus immediately complies. The iron man is under
instruction from Astraea to obey Artegall's commands and does so, but his particular skill
set dictates that, in certain situations and not merely military ones, Talus takes the lead:
"Ne wight but onely *Talus* with him went, / The true guide of his way and vertuous
gouernment" (V.viii.3). Talus does not only protect Artegall's safety; he also preserves his
virtue. In canto iv of Book V, Spenser again extols "that great yron groome, his

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[15] James Nohrnberg, *The Analogy of "The Fairie Queene"* (Princeton, New Jersey: Princeton UP, 1976) 409-425.

[16] Apollodorus, *The Library*, trans. J. G. Frazer (Cambridge, MA: Harvard UP, 1995) 1: III.xv.8.

[Artegall's] gard and gouernment" (V.iv.3). In governing Artegall, Talus becomes responsible for his moral conduct. He is more here than guide or guardian and, by representing Artegall's conscience, Talus once again assumes a role discrepant with his reputation as a strong arm.

Visualizing Talus

Talus' physicality poses another conundrum for scholars keen to establish his form and function. Nohrnberg, speaking albeit figuratively, portrays the Spenserian Talus as "the helpful giant who aids the hero on his quest"[17] and it is this sense of the character's gigantism, whether real or metaphorical, that can all too easily mislead. Spenser's epic poem is full of giants, but Talus is not one of them, despite the early modern commonplace that men of the golden, silver, and bronze ages were larger in stature than their descendants. In fact, references to Talus' role as groom or page suggest a youthful attendant rather than any early modern realization of the monstrous-heroic. His speed and lightness of touch are emphasized as often as his strength:

> His yron page, who him pursew'd so light,
>
> As that it seem'd aboue the ground he went:
>
> For he was swift as swallow in her flight,
>
> And strong as Lyon in his Lordly might. (V.i.20)

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[17] Nohrnberg 417.

Admittedly, Spenser may not have visualized Talus in any specific detail. The iron man's

shape-shifting abilities suggest as much. Missing also from the text is any helpful

description of his apparently iron frame. But these uncertainties warn against the reading of

a singular Talus, one inevitably cast in cruelty and indomitability. To be sure, Talus' iron

casing protects him from physical assault. It also inures him from attempted enchantment.

In canto ii, Pollente's daughter Munera tries to prevent Talus from discovering her "wicked

threasury" (V.ii.9) with spells but no "powr of charms, which she against him wrought, /

Might otherwise preuaile, or make him cease for ought" (V.ii.22). Talus appears

invulnerable to love or seduction. This does not mean, however, that Talus is insusceptible

to emotion. Spenser, in fact, hints at a chink in his armor. Reporting the news of Artegall's

capture and captivity at the hands of the Amazon Radigund to his master's betrothed,

Britomart, Talus betrays some feeling, indeed some fear:

> The yron man, albe he wanted sence,
>
> And sorrowes feeling, yet with conscience
>
> Of his ill newes, did inly chill and quake,
>
> And stood still mute, as one in great suspence,
>
> As if by his silence he would make
>
> Her rather reade his meaning, then him selfe it spake. (V.vi.9)

Talus' lack of "sence," namely the capacity for feeling, appears damning. "Conscience" too may well here denote consciousness rather than any innate moral compass, but Talus is undeniably anxious and significantly aware of the pain he will cause.

Signs such as these of life and sensation in the iron man, partial though they may be, align him closely with the automata and motive statuary that pepper classical, medieval and Renaissance texts. Levels of animation vary but, for the most part, mechanical movement and even magically engendered vitality do not equal life in all its complexity. Such figures have a limited functionality, and Talus seems to be no exception. But his incomplete animation and relative lack of emotion need not suggest a cold brutality. In a poem peopled by elfin knights, giants, dwarfs, monsters and a fairy queen, humanity is actually in short supply. Of course, like other created beings, automata can pose a serious threat to human existence as well as interrogating, via their imitation of life and the hybridization of art and nature they presuppose, the stability of human identity. Posthumanist scholars have lately drawn attention to the cyborg's "destabilization of the 'ontological hygiene' by which cultures have distinguished nature from artifice, human from non-human and normal from pathological."[18] Donna Haraway's seminal text "A Manifesto for Cyborgs" famously celebrates the cyborg as a border or boundary figure, one able, through its hybrid status, to challenge taxonomy and break down the binary distinctions that incapacitate male, female, animal and machine relations.[19] Such a release

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[18] Elaine Graham, "Cyborgs or Goddesses? Becoming Divine in a Cyberfeminist Age," *Virtual Gender: Technology, Consumption and Identity*, ed. Eileen Green and Alison Adam (London: Routledge, 2001) 305.

[19] Donna Haraway, "A Manifesto for Cyborgs," *Socialist Review* 15.2 (1985).

from conventional dualisms would not, however, be universally welcome. Talus'

reputation as a retributive and rebellious automaton[20] and *The Fairie Queene*'s treatment

of analogously manufactured creatures might suggest that Spenser took a dim view of

artificial life and the ontological mobility of such border figures. The Amazons—

interestingly hailed by Haraway as marginal, monstrous and thereby cybernetic—are

severely chastised by Spenser in Book V after Artegall's capture and subsequent

effeminization by their queen.[21] Stripping imprisoned knights of their armor and dressing

them in women's weeds, the Amazons' disregard for the traditional polarity of the sexes

results in harsh punishment and the restoration by Britomart of the women to "mens

subjection" (V.vi.42). As a demonstration of Spenser's attitude towards hybridization and

rule-breaking, not to mention women, this may be instructive; his discomfort with the

performance of gender, and the artificiality it infers, suggests that Spenser was concerned

by the indeterminacy of mixed identities. The complexity of Talus' ontological status,

however, implies that the poet was also conscious of his own partiality and keen to

interrogate it.

Animated Statuary

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[20] Michael West, complicating Nohrnberg's view that Talus 'takes direction rather than giving it' (Nohrnberg 409), emphasises the iron man's 'military ruthlessness' and 'operational autonomy', a common reading based on Talus' unilateral decision-making and apparently uncontrolled violence in the field. See Michael West, "Spenser's Art of War: Chivalric Allegory, Military Technology, and the Elizabethan Mock-Heroic Sensibility," *Renaissance Quarterly* 41.4 (Winter 1988): 667.

[21] See Donna Haraway, *Simians, Cyborgs and Women: The Reinvention of Nature* (London: Free Association, 1991).

Spenser's representation of Talus' closer relations, the artificial and manufactured figures of *The Fairie Queene*, offers a useful insight into the poet's ethical position on the automatous. In the Bower of Blisse episode in Book II, Spenser reconstructs the world of sixteenth-century courtly artifice and automata and seems to do so with serious reservations. Apparently a natural paradise, it soon becomes clear that the Bower's beauty is built on an artistic sleight of hand. This affectation of nature by art, with its "wanton toyes" (II.xii.60), seduces but also deceives and is destroyed by Sir Guyon in a fit of iconoclastic rage. As the Bower's centerpiece, the enchantress Acrasia with her "alabaster skin" (II.xii.77) and "snowy brest" (II.xii.78) is also its icon. Acrasia is one of many animated statues in *The Fairie Queene*.[22] In canto iii of Book V, the false Florimell peddled by Braggadochio, a "glorious picture" (V.iii.25) according to the narrator, recalls the pictorial and sculptural seductions of Acrasia and stands in for the true Florimell at her wedding until exposed by Artegall. The Knight of Justice sets the authentic female, Marinell's true love, beside Braggadochio's living doll:

> Like the true saint beside the image set,
>
> Of both their beauties to make paragone,
>
> And triall, whether should the honor get.
>
> Streightaway so soone as both together met,
>
> Th'enchaunted Damzell vanisht into nought. (V.iii.24)

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[22] See Nick Davis' essay in this volume for a fuller discussion of the automata in Spenser's Bower, among whom he does not, as I do, count Acrasia.

The false Florimell encapsulates several of the classically negative connotations of animated statuary. The level of verisimilitude, usually the hallmark of the great artist, is here a notable hazard, the work of a magician rather than grand master. The underlying insubstantiality or hollowness poses another threat. But the false Florimell is first and foremost a false icon, and the staunchly Protestant Spenser bridles at the image of such a painted, and Catholic, saint. Her movement provokes even greater anxiety. Following the Reformation and the dissolution of the monasteries, rumors persisted, and were cemented by propagandists, of fraudulent sculptural mechanisms discovered in Catholic churches and abbeys. The apparent discovery of several automata in the Cistercian monastery at Boxley in Kent, including a cruciform Christ figure able to move its limbs and even alter its facial expression, perpetuated popular iconomachy and fuelled iconoclastic action.[23] Attempts by both faiths to claim these types of statues and explain their movement indicates the ideological significance of such objects. In Book V of Spenser's poem, the triple-bodied idol of the giant Geryon, allegorically representing Philip of Spain's jurisdiction over Spain, Portugal, and the Low Countries, is found to harbor, beneath its golden façade, a monstrous sphinx. The sphinx, sending forth speeches and her signature riddles, animates the statue above, a debased copy of the ancient Greek oracle. This image of outer beauty and inner monster, a metaphor for the seductive quality but blasphemous

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[23] See Chapter 6 of this volume for Brooke Conti's discussion of the Rood of Boxley. For sixteenth-century iconomachy and its influence on literature, see also Marion O'Connor, "'Imagine Me, Gentle Spectators': Iconomachy and *The Winter's Tale*," *A Companion to Shakespeare's Works, Volume IV: The Poems, Problem Comedies, Late Plays,* ed. Richard Dutton and Jean E. Howard (Oxford: Blackwell, 2003) 365-388.

reality of the Roman faith, is exacerbated by the spectacle of the sphinx herself: "For of a mayd she had the outward face, / To hide the horrour, which did lurke behinde" (V.xi.23). The seductive qualities of these animated statues relate not only to the proselytizing efforts of the Catholic Church but to the inherent sexuality of the sculpted or automated figure. In Book V, Munera, a figure who, with her golden hands and silver feet, is very close to Talus physiologically, mounts an unsuccessful seduction of the iron page. Sexualized artifice is here proscribed, and Talus' apparent asexuality contrasts with the hypersexuality of other, specifically female, automata. These figures each have specific functions to fulfill but it would be wrong to suggest that male and female automata are produced simply for military and sexual purposes respectively. Spenser may question the moral efficacy of several of these hybrid figures but he acknowledges their varied applicability and, in many cases, their genuine value.

What Munera and Talus have in common, besides their cybernetic frames, is their responsibility as guardian statues. The Talos of Apollodorus, Hesiod and Apollonius of Rhodes becomes the guardian of territory, the protector of the island of Crete. If manufactured by Hephaestus, he joins the smith-god's entourage of guardian statuary and metallic automata, including a bronze lion and the gold and silver dogs of Alcinous. Hephaestus typically offered these talismanic statues to rulers or gods for the purposes of protection. Their function was primarily to guard property and such figures had, of course, both real-life and static counterparts. Boundaries, entryways, and thresholds are vulnerable to various kinds of attack and incursion and apotropaic statuary placed at doors or gates were thought to guard against potential intruders or disease. In *The Fairie Queene*, Munera

serves a similar function and guards her father's castle and his wealth. Talus, in the end,

breaches the castle wall and is indeed throughout Book V strongly associated with the

breaking of thresholds but he also acts as guardian statue himself, securing not territory in

this incarnation but personnel. He is Artegall's bodyguard. This does mean, however, that

he spends much of his time as night watchman, guarding the rooms and pavilions housing

his master and his associates. On one occasion, Talus and Britomart spend the night in the

home of a knight they meet on the road. Talus guards the entrance to Britomart's chamber

and Spenser is keen to stress the iron man's dutiful efforts rather than any automated or

programmed behavior. Talus has as restless a night as his anxious mistress:

> Ne lesse did *Talus* suffer sleepe to seaze
>
> His eye-lids sad, but watcht continually,
>
> Lying without her dore in great disease;
>
> Like to a Spaniell wayting carefully
>
> Least any should betray his Lady treacherously. (V.vi.26)

His care is rewarded when Britomart is attacked and he reacts at once to protect her. In

many ways, Talus is the perfect servant. Christopher Faraone, discussing guardian statuary

in the classical period and the brazen man of Greek myth, sets Talos apart from other

examples of the type on account of his ambulatory guardage of Crete. Other guardian

statues animate in various ways, by moving limbs or speaking, but they cannot replicate

the mobility of Talos. The fear that statues might free themselves from their bases and

achieve independence is reflected in several classical texts; Faraone proposes that such a "scenario might help explain why Talos . . . is so readily portrayed in an awful, nearly diabolical manner."[24] The same concern over Talus' independence, as a ghost in the machine, is perceptible in Spenserian criticism but not necessarily supported by the text itself. All Talus' actions are in the service of Artegall or Britomart.

Spenser's portrayal of animated idols and sexualized female automata is also counterbalanced in canto vii of Book V by Britomart's experiences in the Temple of Isis. With Talus barred from entering, Britomart enters the temple to pay tribute to Isis, the epitome of equity, and does so by praying to the Egyptian goddess's "idol" (V.vii.6). Daringly for a Protestant poet who has already indicted the worship of false idols and the animation thereof, Spenser brings the statue of Isis to life. This, however, is not fraud but a genuine miracle. Spenser here rehabilitates the animated statue and suggests that such appearances are not inherently deceptive:

> To which the Idoll as it were inclining,
>
>> Her wand did moue with amiable looke,
>>
>> By outward shew her inward sence desining,
>>
>> Who well perceiuing, how her wand she shooke,
>>
>> It as a token of good fortune tooke. (V.vii.8)

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[24] Christopher Faraone, *Talismans and Trojan Horses: Guardian Statues in Ancient Greek Myth and Ritual* (Oxford: Oxford University Press, 1992) 28.

Not only that, but Britomart, imitating the incubatory habits of the ancients, spends the night in the temple and sleeps at the statue's base. The prophetic dream she has as a result, an allegorical vision outlining the importance of equity and clemency in tempering justice and confirming her future with Artegall, also contains an image of the dreamer herself as the statue of Isis. Artegall and Britomart are clearly the earthly manifestations of Osiris, god of justice, and Isis, but Spenser in this canto, extols the animated statue on several levels. It can, in theory, serve as a conduit for divine communication. It can thereby serve a reliable oracular function, guiding worshippers and predicting the future. Britomart's obvious enjoyment of the image of herself as a statue compensates also for Spenser's prior distaste for the sculptural and sexualized female body. Her transfiguration encourages a healthy narcissism:

> That euen she her selfe much wondered
>
> At such a change, and ioyed to behold
>
> Her selfe, adorn'd with gems and iewels manifold. (V.vii.13)

Talus' exclusion from this sacred episode should not impede his own rehabilitation as an automaton or moving statue. The animation of the statue of Isis, a cult-figure after all, represents one kind of vivification process. The iron man signifies another, no less significant.

Narrative Function

One of Talus' particular skills is the acquisition of hidden knowledge or underlying truth. This has, first of all, a practical application. In his altercation with Munera, Talus not only penetrates the castle walls but sniffs out the hidden treasury and its female guardian:

> But *Talus*, that could like a limehound winde her,
>
> And all things secrete wisely could bewray,
>
> At length found out, whereas she hidden lay
>
> Vnder an heape of gold. (V.ii.25)

Talus' vision too is keen. When Britomart is attacked in the middle of the night in the home of Sir Dolon, the iron man pursues her assailants: "Where euer in the darke he could them spie" (V.vi.30). But Talus' abilities go further than an extraordinary sense of smell, or a piercing night vision. At the start of Book V, Spenser describes how his iron flail "thresht out falsehood, and did truth vnfould" (V.i.12). Distinguishing truth from falsehood is the one of the primary functions of the justice system and Talus no doubt assists his master in this respect. At the end of Book V, Artegall sends Talus after the defeated Grantorto's supporters:

> And that same yron man which could reueale
>
> All hidden crimes, through all that realme he sent,
>
> To search out those, that vsd to rob and steale,
>
> Or did rebel gainst lawfull gouernment;

On whom he did inflict most grieuous punishment. (V.xii.26)

Talus' retributive function in passages such as these can easily take on an inquisitional flavour. C. S. Lewis was unequivocal on the implications of Talus' special talents:

> And when we reflect on the judicial methods of the time, the statement that his iron page Talus "could reveale all hidden crimes" becomes abominable, for it means that Talus is the rack as well as the axe.[25]

Adding torture to Talus' list of malefactions, Lewis simply tows the critical line. But the facility for unveiling hidden truths might suggest, not the work of the torturer, but that of the writer, specifically the composer of allegories. Spenser's description of allegory as "fayned colours shading a true case" (V.vii.2) not only concedes the benefits, not to mention literary necessity, of counterfeiting, but reminds us that establishing truth is a specialist business.

Talus' narrative function has been long overlooked by scholars. As early as Book V's first canto, Talus demonstrates his verbal skills by persuading the murderous Sir Sanglier to return to the scene of his crime and accept his punishment. It is in canto vi, however, that Talus turns true storyteller. With Artegall in thrall to the Amazon Radigund, Talus has few options. He cannot rescue his master because Artegall, abiding pedantically

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[25] C. S. Lewis, *The Allegory of Love: A Study in Medieval Tradition* (Oxford: Oxford University Press, 1936) 348.

to chivalric law, has voluntarily surrendered to the Amazon queen. Talus, always

respectful of Artegall's wishes, instead enlists Britomart's assistance, firstly narrating to

her the circumstances that led up to Artegall's capture: "What time sad tydings of his

balefull smart / In womans bondage, *Talus* to her brought" (V.vi.3). Britomart grants the

iron man an audience and Spenser explicitly likens Talus' spoken version with his own

poetic treatment of recent events:

> With that he gan at large to her dilate
>
>   The whole discourse of his captiuance sad,
>
>   In sort as ye haue heard the same of late. (V.vi.17)

Talus is no mute killing-machine but uses his story-telling faculties to protect Artegall's

fate, and ultimately his reputation, as the Knight of Justice. Talus memorializes both

himself and his master and, by doing so, assumes another of the animated statue's major

roles, that of living monument. He becomes a living monument to justice, a cast iron statue

with flail as sculptural attribute, but he also plays the monument-builder, a role allied to his

narrative function. Book V is full of monuments, mostly negative exemplars, and they are

often erected by Talus.[26] These too are testaments to justice and stark warnings to passers-

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[26] Philip Schwyzer explores Spenser's setting of monumental imagery against figures of dissolution and

obliteration in his *Archaeologies of English Renaissance Literature* (Oxford: Oxford University Press, 2007).

Certainly, a significant tension exists between the desire to wipe out the memory of an event and the need to

consecrate it for future generations. One of Talos's mythical features, a vulnerability at his ankle, remains

unused by Spenser. In several versions of the fable, Talos is finally destroyed when a nail or stopper in his

by; Munera's golden hands and silver feet are "Chopt off, and nayld on high, that all might them behold" (V.ii.26). At the end of the Book V, Talus once again looks to protect his master's reputation. Following the emancipation of Irena, Artegall, like his real-life counterpart Lord Grey, is ignominiously recalled to court. On his journey back, he meets two hags on the road, Envy and Detraction. Grey himself was subject to slanderous attack on his return to London and, although Artegall, Grey's analogue, remains stoic, Talus reacts wrathfully to Envy and Detraction's tirade:

> But *Talus* hearing her so lewdly raile,
>
> And speake so ill of him, that well deserued,
>
> Would her haue chastiz'd with his yron flaile,
>
> If her Sir *Artegall* had not preserued,
>
> And him forbidden, who his heast obserued.
>
> So much the more at him still did she scold,

---

heel is removed and his life blood, or *ichor*, spills out. Ben Jonson, in his 1611 Roman tragedy *Catiline*, likens his doomed rebel to the brazen man and contrasts Catiline's forced monumentalization at the hands of Rome—"So Catiline, at the sight of *Rome* in vs, / Became his tombe" (V.678-685) —with the soldier's own hope of an apocalyptic dissolution:

That I could reach the axel, where the pinnes are,

Which bolt this frame; that I might pull 'hem out,

And pluck all into *chaos,* with my selfe. (III.175-177)

See Ben Jonson, *Works, Vol. V, Volpone, or the fox; Epicoene, or The silent women; The alchemist; Catiline*, ed. C. H. Herford and Percy Simpson (Oxford: Clarendon Press, 1937).

> And stones did cast, yet he for nought would swerve
>
> From his right course, but still the way did hold
>
> To Faery Court, where what him fell shall else be told. (V.xii.42-3)

Critics keen to characterize Talus as the rogue instrument of Spenser's judicial system offer this incident as another example of the iron man's dangerous autonomy. Artegall is forced to restrain him from assaulting the defamatory pair. But Talus' intentions are admirable and the prevention of this honorific if violent action, coming as it does conclusively at the end of Book V, signals not the shutting-down of a recalcitrant mechanism but rather the opportunity for Spenser to appropriate Talus' role himself. With Artegall representing Spenser's berated employer, is it not possible that Spenser allegorized *himself* into the poem as Justice's right hand, the iron man? Spenser's text, and Book V in particular, looks to salvage Grey's reputation, leaving to posterity a living monument to the much-maligned deputy. The author was keenly aware of the power of text as monument, a popular Renaissance literary trope. Maintaining that poetry would outlive any artistic memorials, the sentiment was ubiquitous in the period. Spenser was also deeply conscious of the ability of texts to celebrate both authors and dedicatees. The frontispiece of his 1586 *The Shepheardes Calender* displayed, not Spenser's name, but that of his patron, Sir Philip Sidney. *The Fairie Queene* remains a defense of Lord Grey de Wilton but also a memorial to Spenser's own immeasurable talent. Talus' attempts to protect with arms his master's reputation mirror Spenser's own efforts to eulogize Grey.

While this reading would seem to strengthen claims for Book V as primarily a survey of Spenser's Irish experiences,[27] it also does something else. According to extant sources, the Talos of Greek myth vacillates between the roles of inventor and invented. Is he the nephew of Hephaestus and the producer of cunning contrivances, or Hephaestus' creation and the brazen instrument of war? Spenser's Talus encapsulates the same dynamic. He is both maker and made, and this positions him delicately between nature and art, between subhuman and superhuman status, and between the worlds of antique myth and early modern mechanism. Horst Bredekamp, discussing Goethe's visit to a collection of classical statuary in Mannheim and their magical animation via lights and rotation, reflects on the appeal of the ancient automaton: "Instead of creating the aura of future beings that owed their creation to man, the impression they gave of life resembled more a lofty, past form that relegated modern man to a lower order of being."[28] Such a function is suggested by Spenser's Talus, and this vacillation between autonomy and dependency points not only to the secret history of the iron man but to the secret history of Spenser himself. As a poet in a period of literary patronage, Spenser's authorial independence was partial but his literary identity never in doubt. The automaton in English Renaissance literature inevitably mirrors its maker. For Spenser, Talus offered a timely intervention, a working through of professional and poetic insecurities. For us, he remains a measure of the variety and complexity of artificial life.

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[27] Indeed, if we were to accept the characterization of Talus as a holy terror, this would consolidate speculation over Spenser's guilty conscience as Grey's right-hand man.

[28] Horst Bredekamp, *The Lure of Antiquity and the Cult of the Machine: The Kunstkammer and the Evolution of Nature, Art and Technology,* trans. Allison Brown (Princeton: Markus Wiener, 1993/1995) 6.

Cabaret
Mechanical
Movement

Understanding Movement and Making Automata

Aidan Lawrence Onn
& Gary Alexander

Cabaret Mechanical Theatre

Cabaret Mechanical Movement

CONTENTS

Who, What, Why?

Who?
This book is aimed at people who want to make their own automata. It will also be useful to people who want to make any other sort of mechanical toy / sculpture / device. Design and Technology students at National Curriculum Key stages 3 and 4 should be thrilled. Even if you don't actually want to make anything yourself it will also be useful if you need to understand the practical basics of mechanisms.

What?
The first chapter is a light introduction to the history and principles of movement. This is followed by eight chapters on different types of mechanism. Each of these contains the basic theory and practical tips. The whole book is illustrated with many examples of the automata of Cabaret Mechanical Theatre. The chapter on control is followed by the final chapter which gives a step-by-step guide to design and construction.

Why?
Remember that making machines like this is supposed to be fun. It won't feel that way when you've thrown your latest creation into the bin for the fifth time but please don't blame this book. Just read the relevant parts again and get started on version six.

Thanks
In no particular order, we'd like to thank the following people for their help: The Spooner Family, Tim Hunkin, Sarah Alexander, Alan Chapman, William Jackson, John Lumbus and finally, Sue Jackson, without whom this book probably wouldn't exist.

Some Principles

The theory might help you to understand how mechanisms work. On the other hand, it may put you off making things. If this chapter gets too heavy, try skipping on to something more practical.

The history of automata usually begins around 500 B.C. and you may think that making automata in this digital age is daft and irrelevant. However, the movement of the most complex of today's industrial robots is based on long standing mechanical principles. They use the same mechanisms that are used in the simplest piece of automata or mechanical sculpture.

SOME PRINCIPLES

Before we look at mechanisms it's worth spending a bit of time thinking about what movement is. In this introduction we'll show you some of the basic principles that govern movement and a little of the history of the subject.

Pink Policeman by Ron Fuller

Observation

Just look around...

Everything you see is moving. Electrons are moving in atoms. You and the things you see are rotating with the Earth. Appearances can be deceptive and even when you can see the movement it's not always obvious what is causing it. If you didn't already have an idea of how muscles work do you think you could work out what is going on when you bend your elbow?

Anubis Doing Press-ups by Paul Spooner & Matt Smith

SOME PRINCIPLES

Bird Watcher by Peter Markey
In this piece, turning the handle causes the man's head to turn from side to side. The birds just rotate so their mechanism is simpler. We'll cover these mechanisms in later chapters but can you see how it works just by looking at the drawing?

If you want to make things move be sure to spend some time studying how other things move.

Smallcat! Pay attention now!

Wriggling Fish by Jan Zalud

SOME PRINCIPLES

Principles

All movement is governed by certain mechanical principles. The observation of movement all around you will provide lots of inspiration for your own ideas. But before you create something with mechanical movement it will help you to understand a little about those mechanical principles.

The Barecats by Paul Spooner and Matt Smith

Who is winding-up whom? When the small cat points the big cat looks up. When you look at mechanisms try to work out which part is driving and which part is driven.

Machines

A machine is something that modifies FORCE. For example, a unicycle is a machine. When the force comes from an outside source, it's called INPUT. The mechanical action of the machine produces OUTPUT. So, legs pushing the pedals (Input), produce a rotating wheel (Output). The motions and forces that occur between Input and Output are described by the science of Mechanics.

SOME PRINCIPLES

Mechanics

The science of mechanics has been studied for a very long time. The origins can be traced back to the early dynasties of ancient Egypt.

The first recorded scientific foundations for mechanics were developed in the 3rd century BC by a Greek mathematician called Archimedes. He worked out formulae for the equilibrium of simple levers and centres of gravity.

What's equilibrium?

Equilibrium means the state of balance.

Archimedes' classification of levers into three different types persists to this day. (Levers - chapter 2)

Another important historical development was recorded almost two thousand years later by Galileo Galilei (born 1564). He studied the theories of Archimedes and in particular, the use of mathematics to solve physical problems. Galileo advanced Archimedes' work on mechanics by developing the science of Dynamics.

Dynamics deals with bodies in motion. It is the study of the forces and motion of moving parts.

Oh

SOME PRINCIPLES

In the year that Galileo died (1642), Isaac Newton was born. He introduced the concepts of force and mass. From this he formulated his Three Laws of Motion.

Newton discovered that motion does not require force. Force is only required to accelerate or decelerate motion.

Law Number One

Basically, any moving object will continue in a straight line and at a constant speed indefinitely unless some force interferes with its motion.

In reality, a moving object usually slows to a stop because friction or air resistance drain its energy.

Right! Let's get on with making something now.

SOME PRINCIPLES

Law Number Two

Newton's second law relates the acceleration of an object to the forces acting on it. It's not too hard to understand:

The greater the force, the greater the acceleration.

Therefore, a force acting on a moving object will speed it up, slow it down, or change the direction in which it is moving. A force acting on a stationary object may start it moving.

Running Men by Peter Markey
The front foot of each of the runners is attached to a crank. The cranks are offset from each other so that each runner moves forward at a different time. (Cranks - chapter 4)

SOME PRINCIPLES

Newton's third law expresses the equality of action and reaction. A principle that can be demonstrated by the case of a rocket launch.

Law Number Three

The downward expulsion of gases causes a reactive force that drives the rocket upward.

So, if an object is pushed or pulled, it will push or pull equally in the opposite direction.

These laws of classical mechanics - or Newtonian Mechanics, as they are sometimes known - play an important part in understanding mechanical principles. Whether or not they are any help when it comes to making things is debatable.

Okay. Now I know something about mechanical principles. What's all that got to do with making automata?

Oh dear...

SOME PRINCIPLES

A-ha! An automaton IS a mechanical system!

Let's have a look at some mechanical systems now.

All mechanical systems are made from combining the same basic mechanisms. It can be shown that there are really only 5 basic mechanisms. These are;

1. The Inclined Plane, or a slope
2. The Wedge
3. The Screw
4. The Lever
5. The Wheel

However, the wedge is like an inclined plane, or two inclined planes joined together, and the screw is like an inclined plane wrapped around a shaft. The wheel is like a lever which rotates through 360°. This means that there are really only two basic mechanisms - the lever and the inclined plane - and all other mechanisms are based on them. We've divided the next part of the book into eight chapters which cover the most commonly used mechanisms.

Levers

All machines, including automata, will almost certainly employ at least one lever. Of course, if a machine only had a single lever it would be quite a simple thing and most machines will use a combination of levers and other mechanisms.

However, it's still possible to have some fun with single mechanism machines and levers are the best place to start.

A lever is a very simple device. It consists of a rigid bar which pivots (turns) on a fixed point. This pivot point is called the Fulcrum.

Archimedes wrote lots of books on mechanical principles. In the one called 'On the Equilibrium of Planes' he establishes the 'Law of the Lever'.

> Levers are used to convert a small effort...

> Into a large effort!

LEVERS

Yes, and vice versa.

Brilliant! That'll make life easier.

Archimedes once said:

Give me a long enough lever and a place to stand and I will move the Earth..

Archimedes may have been very clever but he wasn't Superman. To operate his lever he would have needed a very big fulcrum and we're not sure what he was going to rest it on. Also, to gain this super mechanical advantage the load, in this case, the Earth, would need to be close to the fulcrum and the lever would need to be very, very long. Of course, Archimedes knew all this and space suits weren't invented anyway.

As with the opening chapter, you might want to skip some of this theory. However, levers are key to understanding mechanisms and there are real world examples of each type to help you through.

Archimedes divided levers into three separate types (or orders). Each one has the fulcrum, load and effort arranged differently.

A Lever of the First Order

LEVERS

By moving the fulcrum closer to, or further away from the load, you change the distance the lever must travel and the amount of effort required to move the load.

> That's it. This is a lever of the first order.

A pair of scissors is an example of a lever of the first order. The effort is applied to the ends held in the hand. The load is at the cutting edges. The fulcrum is the rivet or screw which holds the two halves together. If you experiment, you should find that it's easier to cut thick paper when it's closer to the fulcrum.

effort

load

fulcrum

A lever of the first order always has the fulcrum located between the load and the effort.

LEVERS

Sheep Shearing Man by Ron Fuller

The man goes up and down and on every twelfth turn of the handle he stays up long enough to have his head chopped off by the scissors. Luckily, the head is attached to a string so it's pulled back with the next turn

So... is that all the theory?

I just want to tell you about Mechanical Advantage.

I thought you might.

Mechanical Advantage

Mechanical Advantage is just a comparison (ratio) of the effort put in to the load moved. The leverage is the ratio of the distances of the effort and load to the fulcrum(A and B below). When we look at these ratios we can tell how the lever will work.

effort   load

A   B

In this example, the leverage is the ratio of A and B, which is 6:2, or 3:1.

Mechanical Advantage $= \dfrac{\text{Load}}{\text{Effort}}$

So, an effort of 1 could move a load of 3, but as you'll probably have realised by now, you will have to move the effort end of the lever three times as far as the load end moves.

LEVERS

On the left, four tins of cat food are two units away from the fulcrum. On the right, four tins of cat food are two units away from the fulcrum.

The Mechanical Advantage is 4/4 = 1. Because the distance to the fulcrum is the same on both sides it should be obvious that the tins will balance.

In the next example the fulcrum is off centre. This means we have some leverage and a mechanical advantage.

On the left, one tin of cat food is eight units away from the fulcrum. On the right, four tins of cat food are two units away from the fulcrum.
The Mechanical Advantage is 4/1 = 4. The leverage is also 4 (8:2 = 4:1) so the tins will still balance.

In many situations, mechanical advantage will be less than the calculated value because we have to take account of friction.

LEVERS

A Lever of the Second Order

Here the load lies between the fulcrum and the effort. This kind of lever can be described as a force magnifier, having very good mechanical advantage.

The wheelbarrow is an example of a lever of the second order. It is used to overcome the resistance of a heavy load by using a small force. To achieve this mechanical advantage, the wheelbarrow obeys a rule that applies to all force magnifiers: The effort must move a greater distance than the load.

Lifting the handles using a relatively small effort raises a heavy load. The fulcrum is the axle of the wheel.

Nutcrackers are another example of a class two lever. Because a class two lever is a powerful force magnifier, the toughest of nuts can be cracked with a relatively small effort.

A Lever of the Third Order

In a class three lever the effort is applied between the fulcrum and the load. This kind of lever can be described as a force reducer since the effort will always be greater than the load.

LEVERS

This may not sound very useful but in certain cases it may be the only possible arrangement. It also has the advantage that the load moves faster than the effort. So you could call it a movement amplifier.

Your arm is an example of a class three lever, with your elbow as the fulcrum. The effort comes from the bicep muscle which attaches to your forearm just below the elbow. The load, held in your hand, requires effort from the muscles to pull up against the fulcrum.

The ladder below is a class three lever. The effort to lift the ladder, or hold it in place has to be applied between the load and the fulcrum. So the higher up the ladder the fireman goes, the greater the effort needed to support him.

LEVERS

A fishing rod is another class three lever. One hand acts as the fulcrum while the other applies the effort to move the rod up and down. The load is the weight of the tackle, bait and perhaps, a fish - which is raised a long distance by a short movement of the hand.

Most levers you'll encounter will be 1st or 2nd order. 3rd Order levers are used in situations where the other types are impractical or when they give another advantage. For example, a pair of tweezers (3rd Order) are easier to control than a pair of pliers (2nd Order) because the effort is applied closer to the load.

An Allegory of Love by Paul Spooner
The man keeps trying to hit the nail on the head but always misses on either side.
This is mainly because the nail moves as well!

Practical

When designing a mechanism which uses any of these three classes of lever remember that the movement of a lever will always be through the arc of a circle and not in a straight line.

Get some cardboard and 2 pins. Cut out a long straight piece (your lever) and a circle. Experiment by pinning them down onto another piece of card as shown on the next page. Pin the circle down off-centre.

Rotate the circle and notice how it moves the lever. Try changing the pivot point (fulcrum) of the lever. Then try moving the circle closer to lever's pivot point.

LEVERS

You should see that positioning the circle close to the fulcrum is equivalent to trying to push a door open near its hinges.

Make pencil marks on the backing card to indicate how much the lever moves in different arrangements.

You've probably realised that the circle is a cam (chapter 5). This combination of cam and lever is one of the most common mechanisms in automata making.

It's often a good idea to make flat representations of your mechanisms from card. It allows you to test ideas very quickly and cheaply. The method shown above could be used to decide on the size, shape and position of a cam when you know how much movement you need from the lever.

You might want to consider how you could use the cam and lever mechanism in your own design.

Shafts and Bearings

If you're just beginning to make moving things it's easy to overlook the importance of shafts. A rotating shaft, or axle, often has all the other mechanisms attached to it, so if it's not running smoothly it's likely that the rest of the machine will have problems too.

1 - The handle (a crank)
2 - An eccentric cam lifts the Lion tamer up
3 - A pin wheel rotates the lion tamer
4 - A snail cam opens the lion's mouth

In this piece, the Lion Tamer (by Ron Fuller) spins and drops his head into the lion's mouth. As the lion's mouth closes, the lion tamer moves out of reach. For this sequence to remain constant the mechanisms are fixed to the shaft so that the lion's mouth is always open when the lion tamer's head is in his mouth.

We will be covering each of the Lion Tamer's mechanisms in more detail later.

SHAFTS

Shafts can be anything from a piece of stiff wire or a wooden dowel to an accurately engineered steel rod. The part with the hole that supports the shaft is called the bearing.

Shafts should be strong enough to support the mechanisms they carry and the right size to fit the bearings that they run in. Not too tight and not too loose.

Bearings

To keep the rotating shaft stable and to help it to run smoothly it is supported by a bearing.

The bearing and shaft need to be chosen together. If all your components are heavy and you use a steel shaft you don't want to have it supported by a thin plywood bearing. Even if the machine works for a while, you'll probably find the shaft eventually makes the bearing hole bigger. That is, friction will wear out the bearing.

Sometimes the bearing is made by simply drilling a hole but if better support or less friction is needed something more substantial might be called for.

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SHAFTS

Ball Bearings

If you've ever tried inline skating with an expensive pair of skates you'll know that the wheels turn very easily even with the heavy load of your body weight on them. This is because they have good quality bearings. The simplified illustration below shows how they are put together.

OUTER RACE
STEEL BALLS
INNER RACE

The outer race is fixed and the inner race rotates with the shaft. Because the balls can roll with a small area of contact with the races, the friction is very low. They are made very accurately from hardened, polished steel which also helps to reduce friction.

You should try to constrain the movement of shafts so that they only move in the way that you want them to. For instance, if you only want the shaft to rotate try to ensure that it doesn't move sideways.

Sit-up Anubis by Paul Spooner
A simple wire shaft is bent at one end to make a handle. A thin shaft works because the moving parts are so light.

In this simple example the shaft passes through a single bearing. It's attached to a handle and a disc. You could copy this with two pieces of cardboard and a drinking straw. Try it and see what problems you have. Make the hole in the disc off-centre and see how much weight you can lift up and down.

Here, a second bearing has been added to provide better support to the shaft. The discs, or collars, at each end of the shaft stop it from moving from side to side.

PLAN VIEW

SHAFTS

Shafts don't only rotate in bearings. The snail cam shown here pushes a shaft upwards. This shaft also needs the support of a bearing.
If the bearing (in this case, just a hole) is too big, the shaft could easily move off-centre causing extra friction or jamming.

The same effect can occur if the bearing is too thin to provide adequate support, or if it's too far from the cam.

By adding thickness to the bearing the up and down movement of the cam follower is much more predictable. The diameter of the hole which forms the bearing should be just big enough to allow free up and down movement.

The additional u-shaped
bracket shown here is
a way to position a
bearing as close as
possible to the end of
the shaft where the
cam is pushing up.

Whenever bearings are working in pairs you need to take
care that they are properly aligned. For example, if the
bearings are holes at each end of a box, you could design
the box so that the ends could be drilled at the same time.

If you're working in wood and using dowel for shafts, then
it's always worth test drilling. You will find that the
diameter of the dowelling can vary. A couple of test drillings
(with a sharp bit!) into scrap wood will tell you which drill
bit to use for your bearing holes.

SHAFTS

Fixing

You also need to think about how you will fix your cams and other mechanisms to the shaft. Below are three practical methods for avoiding the problem of the cam slipping on the shaft.

1 - Pin the cam. A pin is pushed through a pre-drilled hole into the cam and the shaft.

2 - Cam with hub. The hub is part of the cam or glued to it. A screw passes through the hub and into the shaft. This keeps the fixing away from the radial surface of the cam.

3 - Screwed cross pin. This is similar to 2, but easier to make. A wire, or split-pin passes through the shaft only. A screw in the cam holds it in position.

Yet another way is to have a square shaft. This is provides good fixing between the cam and the shaft, but it's harder to make square holes in your cams. You also have to make the square shaft round at the ends if you want it to rotate smoothly.

If you decide to glue the cam and make the fixing permanent, you might want to give yourself a way of removing the complete camshaft from its box / bearings.

Cranks

A crank is a lever attached to a rotating shaft. Sometimes the crank is used to turn a shaft - for instance, when it is used as a handle, and sometimes the crank is driven by the rotating shaft. In this case the crank will change the type of motion.

A Crank converts a rotating motion into a reciprocating motion.

What's a reciprocating motion then?

Reciprocating motion means to go with alternate backward and forward or upward and downward motion.

Fascinating...

CRANKS

Shaft
Guides
Vertical
Rod
Pin

The circular disc, with the pin, forms a crank on the end of the shaft. The pin connects to the vertical rod (it has to be loose enough to allow the crank to rotate). The movement of the vertical rod is constrained by the guides. When the shaft rotates the vertical rod moves up and down like a piston. This up and down movement is called reciprocating motion.

So the crank is converting the circular motion of the rotating shaft into the up and down motion of the rod.

The centre of this rotating shaft is known as the axis.

The diagrams below show the crank in four different positions.

Diagram One shows the vertical rod at its highest position.
Diagram Three shows the rod at its lowest position.

The difference between the rod's highest and lowest positions is shown in this diagram. The lines indicate the amount of vertical movement created by the crank.

CRANKS

CRANK
PIN

PLAN VIEW

The rotating shaft will often need to be supported (by bearings) on both sides of the crank. In this case, the crank will look more like the illustration above.

The arrows in this diagram also show the 'throw' of the crank. The throw of a crank is the diameter of the path it travels.

In this sequence it can be seen that the crank pin (black) is simply repeating the motion of the handle.

CRANKS

CRANK PIN 2

CRANK PIN 1

EXTRA BEARING

PLAN VIEW

You can add as many cranks to a shaft as you want but you will probably need extra bearings to support the shaft.

You can also offset the cranks from each other so that they are in different positions at different times. In the example above, when one crank is up, the other is down .

Let's look at some different ways we can use cranks to operate levers.

Here the crank will lift the lever through a small arc as the shaft rotates. Gravity will tend to keep the lever in contact with the crank pin. There's an assembled view on the next page.

Gravity

Gravity is the force that attracts bodies to the centre of the Earth. This happens because objects are attracted to each other with a force which is proportional to their mass. The Earth has a lot of mass so it pulls all the smaller objects towards its centre.

Apples and levers, moons and planets are all governed by the same law of gravity.

CRANKS

Here a lever is raised and lowered because it is resting on the rotating crank pin.

Number 1 shows the lever in its lowest position and 3 shows it in its highest position.

If the shaft rotates at high speed it is possible that the lever will not stay in contact with the crankshaft. If the lever is struck hard it may bounce up higher than expected. Also, It may not have time to fall back while the crank shaft is at the lowest position. The next design overcomes these problems.

CRANKS

In this design the crankshaft passes through a slot in the lever. This means that the lever is driven up and down by the crank. This 'positive' connection doesn't rely on gravity and the lever should always move through its expected path.

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CRANKS

Jumping Nurse by Paul Spooner

The nurse has joints (shoulders, elbows, etc) which are loose enough to give a bit of "extra" movement when she's pushed up in the air by the crank and cam mechanism. The bead on the handle can rotate. This makes the crank handle easier to turn.

BACK
CRANK

FRONT
CRANK

HANDLE

Dancing Girls by Peter Markey

The handle rotates a crank at the back which is connected to a crank at the front. You can see that the connecting piece has two slots which allow the cranks to rotate. Can you work out how the front crank will move? (Clue: It doesn't do a full revolution).

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Practical

Although cranks seem simpler than cams they can be harder to make. A cam on a shaft has only one fixing point but if you make a crank from parts there are four points to fix.

A tip for getting the shafts to line up is to make the crank on a single piece and then cut out the part you don't want when the glue has set.

Whichever way you construct the crank it's important to make sure that everything is "square" (at 90° or parallel), in alignment and firmly fixed. Work out the throw of the crank first because it will be hard to change after you've made it.

CRANKS

However, wire is quite easy to change, so see what you can do with a pair of pliers and a coathanger (welding rod may be easier if you happen to have some).

If you've read everything so far but still haven't got your hands dirty then maybe it's time to start. You will learn much more about the practicalities by playing with materials and mechanisms than by reading.

If you've never made anything mechanical you might be tested by the simple device above. We've left out lots of information, but here are some points to consider: What material will you use for the lever pivot? If the string pulls down the lever, how will it go back up? How can you stop the string from slipping off the crank?

If you find it easy, attach something to the lever. How about a jointed leg and foot? Add another crank and another leg and you'll have a pair of dancing legs.

Don't be scared - make a mess with cheap materials and don't be put off if it's a struggle.

Cams

Like cranks, cams can also turn a rotary motion into an upward and downward motion. But they can also do lots of other more complicated things. Cranks are useful but you can have some real fun with cams.

Cams come in many shapes. The two on this page are called lobed cams because they have lobes. A lobe is just an addition to the circular shape.

The shape of this cam means that it should only be turned one way. If it turns the wrong way, it will jam against the follower.

Which is the wrong way Barecat?

CAMS

As with cranks, the throw of a cam and the amount of movement it creates, is the distance between the maximum and minimum radii. This diagram shows the difference between the lobed cam's highest and lowest points. The arrows (at 'Difference') indicate the amount of movement or throw created by the rotating cam.

The lobes on this cam will produce a steady upward motion followed by a sudden downward motion.

Four times per revolution?

Right!

One complete revolution of the cam is called a cycle. For the four-lobed cam there will be four distinct events per revolution. The timing of the events in a cycle depends on the speed of rotation.

This cam will produce one event per revolution. Not surprisingly it's known as a snail cam.

These lobed cams will produce two, three and five events per revolution. You can probably guess that to produce a very long sequence of events you need more space on the cam profile. That means you need a bigger cam.

Who are you calling eccentric?

In this illustration, the variation of the cam's surface from the axis will cause a follower to either lift or drop.

rotating shaft

radial surface

axis (or centre of rotation)

CAMS

It is also possible to make a cam from a circle. You do this by moving it's centre of rotation. This type of cam is known as an eccentric cam and The part that the cam moves is called the follower. This is because it follows, or tracks, the profile of the cam.

no change   change

concentric   eccentric

So, being eccentric just means that you're a bit off-centre. If you take a circle and rotate it off-centre you'll have an eccentric cam. This produces a very smooth movement which makes it good for lifting heavier loads. Be careful not to make the eccentricity too extreme though.

If a cam is concentric, its radius is constant. That means it won't change the position of the follower.

Durrrr. Obvious!

This cam has a raised and a dipped radius. At the points where the profile returns to the constant radius no movement will occur in the follower. This part of the profile is known as a pause or dwell angle. You can see this more clearly in the sequence below.

plus radius
lift of follower

Dwell or pause

minus radius
drop of follower

Dwell

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CAMS

Getting Practical

It's one thing to draw a cam that does exactly what you want but it's another thing to make one that actually works.

Firstly, remember the previous advice about bearings. A smooth and true running shaft is always a good starting point. As well as the camshaft, don't forget to consider the shaft which the follower is attached to - this should be well supported too.

Don't try to get a massive movement out of a tiny cam. Think of the cam as a lever - more leverage will make the work of the cam easier. So a bigger cam will produce small movements relatively easily.

The shape of the follower where it's in contact with the cam is an important design point. You need to consider how it will follow the profile of the cam. A sharper point on the follower will be more able to track intricate variations (1, below). The other important consideration is friction and if you want to reduce it, then it's a good idea to use a free-running bearing or roller (2).

You also need to consider the direction of rotation. Some cams, like the snail cam, will jam against the follower if they rotate in the wrong direction.

A lot of the simpler machines that are sold in Cabaret Mechanical Theatre use cams to rotate a follower and produce rotation in a different plane. Strictly speaking, this sort of mechanism is a friction drive (chapter 9). The cam and follower are working like a pair of gear wheels at right angles to each other.

For example, the fire in the Dragon's mouth (below and front cover) moves from side to side as the top jaw moves up and down. In the diagrams you can see how it works.

Dragon by Peter Markey

The cam on the left lifts and rotates the follower clockwise (if viewed from above). Then the second cam, on the right, lifts and rotates the follower anti-clockwise. So, a single mechanism is acting as a cam and a friction drive.

The small pins on either side of the follower stop it from rotating too far.

CAMS

It should be clear that using cams this way is not terribly
efficient. However, these mechanisms work well enough for
use in simple wooden toys. In more serious applications,
you might use bevel gears to achieve the same result. We'll
look at these later.

Cams for Memory and Switching

Unlike cranks, cams have the ability to store information.
So another way to look at cams is as the mechanical
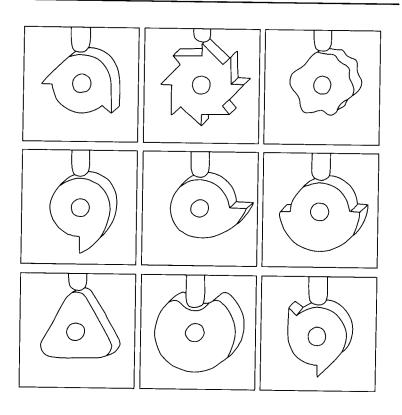version of a computer program.

The information is stored in the shape of the cam. As the
cam rotates, this information is retrieved by a cam follower.
The follower tracks the cam's profile reproducing the same
movement for each revolution of the cam.

A series of cams on a single shaft can carry out quite
complex programs. This is the way a lot of industrial
processes were controlled before microprocessors took over
and you might still find older washing machines with cam
timers to control their various functions.

In these sorts of examples the cams operate switches which
then operate relays, motors or other electrical devices. This
is a way of simplifying, or replacing, the mechanisms in a
machine.

Motor with
crank   Electrical
         connection

         Cam
         timer

                 Linkage

                 Cam with
                 lever

Two different approaches

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OK Smartcat. Some of these cams will work if you rotate them clockwise, others will not... Find the four that wont work.
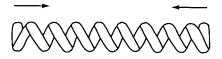
Springs

Springs have the ability to return to their original shape after stretching or compressing. This means they can be used to keep other components together or apart. Like cams, springs are also memory devices because they can be used to 'remember' a position and return to it after a particular action has occurred.
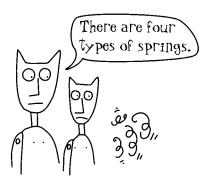
Springs come in lots of different shapes and they can be used in a number of different ways. These are the four basic types:

Compression (Push) Spring

Extension (Pull) Spring

Torsion Spring

There are four types of springs.

Radial Spring

SPRINGS

The definitions of spring types can be a little confusing. For instance, an elastic band can be used as an extension spring (firing pieces of paper across the classroom), a radial spring (stopping a rolled up poster from unrolling) or a torsion spring (driving the propellor in a model aeroplane). So you shouldn't worry too much about the correct names.
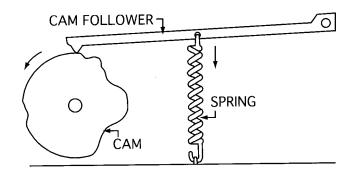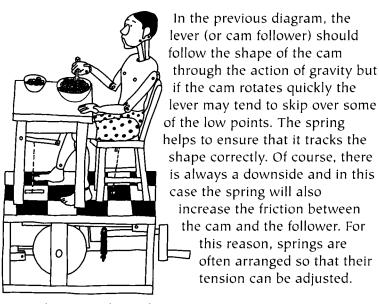
Laminted leaf Spring

Coiled, or Clock Spring

The leaf spring above is a special type of compression spring that is used in the suspension system of some cars. The clock spring is a type of torsion spring. In a clockwork toy, winding it up tightens it and the winding energy is stored in the spring. As it unwinds slowly the energy drives the mechanism which operates the toy.

A common example of spring usage would be when you need to keep a lever against a cam so that it follows its profile correctly.

CAM FOLLOWER

SPRING

CAM

In the previous diagram, the lever (or cam follower) should follow the shape of the cam through the action of gravity but if the cam rotates quickly the lever may tend to skip over some of the low points. The spring helps to ensure that it tracks the shape correctly. Of course, there is always a downside and in this case the spring will also increase the friction between the cam and the follower. For this reason, springs are often arranged so that their tension can be adjusted.

How to be Foreign by Paul Spooner

Most door handles have springs inside. After you've pulled the handle down to open the door, you want the handle to return to the up position with the latch out to hold the door closed.

Have a guess what sort of spring is usually in a door handle.

errr...

A: Torsion

SPRINGS

In Practice

You may find it's easier to use a weight instead of a spring. In the cam example, a weight would give a constant load, whereas the load would vary with the spring. It may also be easier to adjust a weight.

If you do use springs, you may find yourself making your own from spring steel wire (piano wire) because all the springs you can find are either too strong or too weak. Old typewriters and small domestic appliances can be a good source for light springs.

If you ever meet an automata maker who boasts about his˙ fine and extensive collection of springs, ask him how many he has ever used.

˙his - only men boast about such things.

Linkages

A linkage is a connection that transfers motion from one mechanical component to another. Sometimes a linkage is a lever. So this is another occasion when you shouldn't worry too much about the terminology.
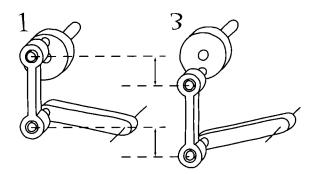
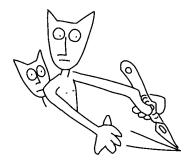This exploded diagram shows a linkage connecting a crank to a lever.

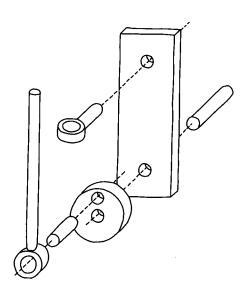As the crank rotates, the linkage transfers motion to the lever.

LINKAGES

The difference between the lever's highest point (1) and the lowest position (3) will always be equal to the throw of the crank. The length of the linkage will not affect the distance travelled.
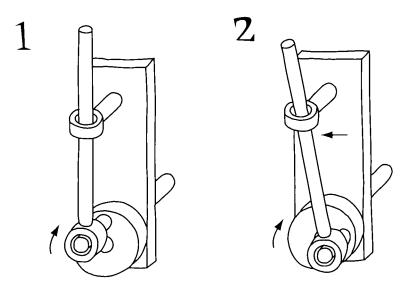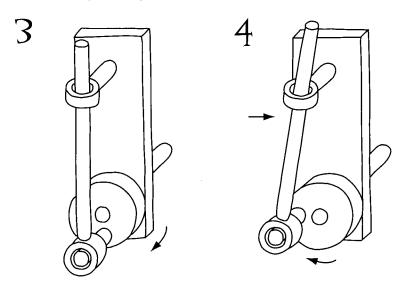

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The Crank Slider

In this diagram the lever's motion is restrained by a bearing which allows it to slide up and down with some side to side movement. This mechanism is known as a crank slider.
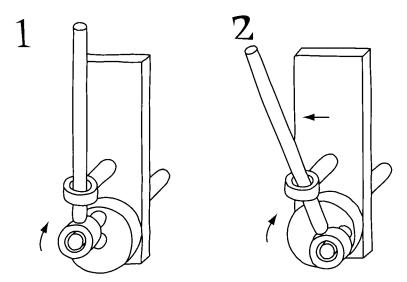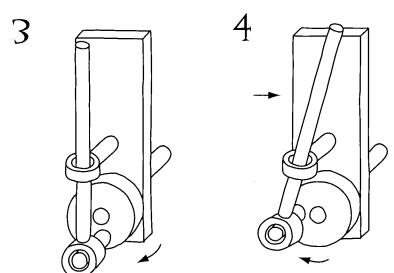
LINKAGES

Crank Slider with high bearing

As the crank turns it pushes the linkage up and down and from side to side. The amount of sideways movement can be altered by moving the bearing up or down.
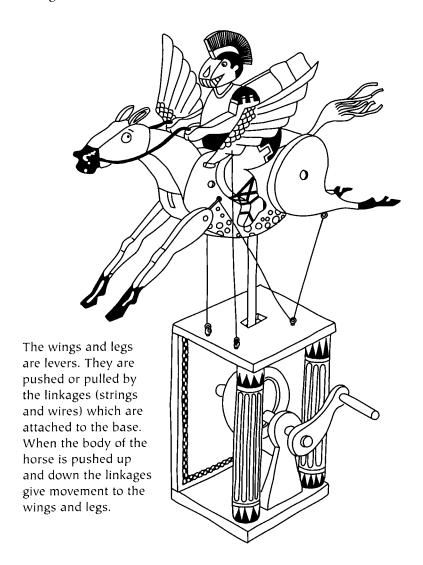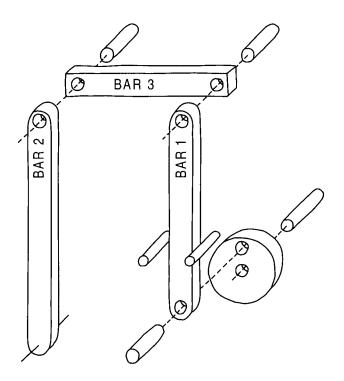
Crank Slider with low bearing

The closer the bearing is to the crank, the more sideways movement there will be. The high and low points remains the same.

LINKAGES

The Birth of Fast Food by Keith Newstead

The up-down / forward-back movement of the horse is produced by a crank slider similar to the previous diagrams. Additional movement in the wings and legs is gained by the clever use of linkages.
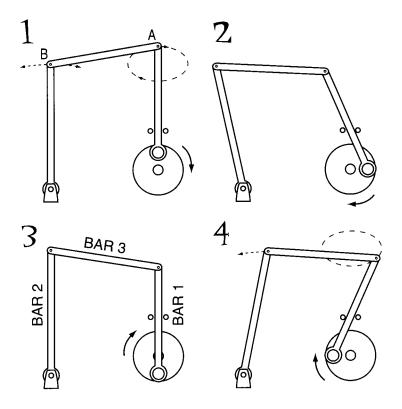
The wings and legs are levers. They are pushed or pulled by the linkages (strings and wires) which are attached to the base. When the body of the horse is pushed up and down the linkages give movement to the wings and legs.

The Three Bar Linkage

We've seen how levers move through the arc of a circle so what happens if you want the movement to be in a straight line? Here's one way...
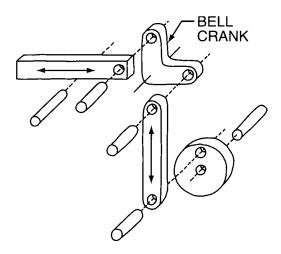
This exploded diagram shows a three-bar linkage. It transfers the rotating motion of the crank via bar 1 and bar 3 to a side-to-side motion of bar 2. The pegs beside bar 1 limits its movement and stop it rotating too far with the crank. The sequence on the next page makes the action clearer.

LINKAGES

The crank-slider arrangement makes the top of bar 1 describe the shape of an ellipse (A). Bar two is a lever with a fixed pivot point at the bottom. Bar 3 connects the other two bars so that the top of bar 2 (B) approximates a straight line movement.
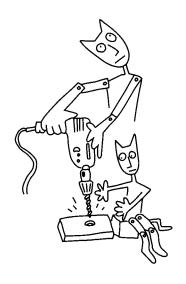
You can see from the diagrams that you don't get a perfect straight line but it's worth understanding the effect. The rotary action of the crank, is turned into an ellipse and then an arc by constraining levers at different points.
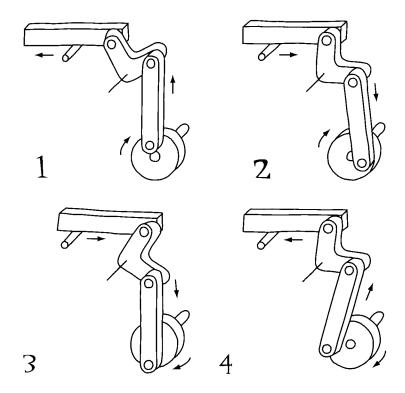
BELL
CRANK

Going Another Way - The Bell Crank

A bell crank linkage is useful for changing an up-down movement to a side-to-side movement or vice-versa. The diagram shows a crank which pushes the vertical rod up and down. The bell crank rotates around its pivot point and moves the horizontal rod from side to side.

LINKAGES

1

2

3

4

The bell crank is really just another type of lever so the amount of movement can be increased by making it bigger or smaller. You can also make one end of the bell crank longer or shorter to change the amount of leverage.

ding
ding

It would be possible to devote a whole book to linkages but we only have space to cover a few. However, if you've understood everything so far you should be able to look at machines and find some more for your notebook.
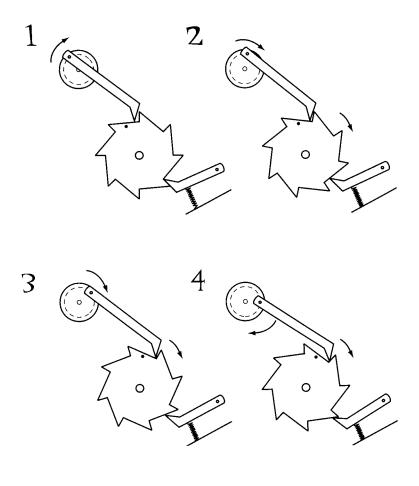
Ratchets

Up until now we've been looking at mechanisms which give a continuous motion - as long as there is an input there will be an output. The ratchet is a mechanism which gives a motion that is not continuous. This is known as stepped or intermittent motion.

PAWL

RATCHET

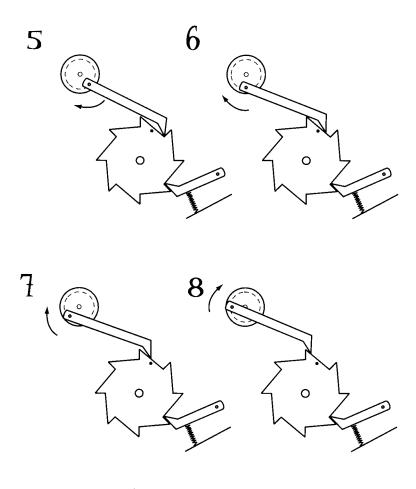PAWL
(OR DETENT)

The ratchet is a wheel with notches cut into it. A pawl pushes against the notches and drives the wheel around in steps. A second pawl (or detent) stops the wheel from slipping back.

Some screwdrivers have ratchets so that you can keep the driver in contact with the screw. You have to set a switch so that the ratchet turns in the right direction for tightening or untightening.

RATCHETS

In the sequence shown here the ratchet is driven by a
crank. One revolution of the crank moves the ratchet one
step. So the crank has to turn 8 times to complete one turn
of the ratchet wheel. In the diagrams, the dot on the ratchet
shows how far it turns with one turn of the crank.

RATCHETS

Ratchets are also used as a locking mechanism to stop **PUSH TO** wheels from turning **RELEASE** the 'wrong' way. In this illustration a heavy weight can be moved in short steps as the pawl stops the ratchet from turning very far in the anticlockwise direction. A release mechanism on the pawl is provided to allow the lift to be lowered.
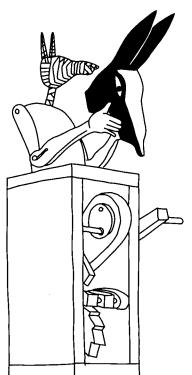
Head Off Anubis by Paul Spooner

The handle turns an eccentric cam which pushes a ratchet wheel around in steps. The rachet's shaft also has a snail cam on it. This is used to pull the arms forward. Other linkages, levers and a spring complete the mechanism. Anubis takes his mask off in steps to reveal mummy wrappings, but then it snaps back on very quickly.

Poisoned Milk by Paul Spooner

In this piece the milk is made from leather which is pushed up, rapidly from below. The movement of the leather is what makes the tongue move up and down but when you look at it, the cat appears to be lapping. This method avoids running a complex mechanism through the body to the tongue and is typical of Paul Spooner's approach to making automata.

The cat laps enthusiastically at the spilt milk for a while. Then it collapses in a heap. The body is loosely jointed and held together by string. When the string is released the cat falls down in a fairly random way. The lack of stiffness in the string makes it difficult to control but it's ideal for this piece.

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RATCHETS

Another mechanism which produces intermittent motion is the Geneva wheel. This is used in cinema film projectors and cameras to step the film on one frame at a time.

GENEVA
WHEEL

DRIVE
PIN

DRIVING
WHEEL

This is really a specialised form of cam but it's in this chapter because it's a mechanism for intermittent motion. Can you see how it works?

Another Practical

Try making your own ratchet wheel using the diagram below as a guide or a template. Use thick card to start with and see if you can make a crank the right size to drive it. It's getting hard now, isn't it!

If you're stuck, try making a flat crank, (like the one in the 8-step ratchet diagram on pages 78-79), pinning everything down on a board and working it out by trial and error.

Template / Guide for a Ratchet

Drives & Gearing

Like linkages, drive mechanisms connect other mechanisms together but in this case we are talking about rotary to rotary connections - things like pulley wheels and bicycle chains. A drive mechanism may also involve gearing or changing the angle or direction of movement.

Drives can be split into two types.

Positive   Friction

Positive — Friction

A positive drive is one where the input and output are locked together in synchronisation. A friction drive, as its name implies, relies on friction to transfer the movement. As usual, it's clearer if you look at examples.

DRIVES & GEARING

Teeth Locked Together

The wheels in this positive drive have teeth around their radial surfaces. (Toothed wheels like this are sometimes called sprockets). The teeth engage with the holes in the belt. This means that the driven wheel will duplicate the movement of the driving wheel. The wheels are locked together.

Photographic film uses this principle.

A Frictional Connection

The drawings that follow have been simplified for clarity. They would normally have flanges to stop the belt slipping off the sides. This drive has plain, toothless wheels, so it uses the friction between the radial surface of the wheels and the belt to transfer the motion.

DRIVES & GEARING

A number of factors can affect the efficiency of this type of drive. If there is too much friction (for instance if the belt is too tight) the wheels may be difficult to turn. If the belt is too loose it may just slip around the driving wheel and fail to transfer any motion.

To overcome the problems of too much or too little friction there is often a mechanism to adjust the tension of the belt. The tensioning device shown here is known as an idler or jockey wheel. It can move to take up any slack in the belt. It also has the advantage that it increases the amount of belt that is in contact with the wheels, therefore increasing the friction and efficiency.

The following diagrams show most of the ways belts can be used. This is the drive we've seen already. If we assume there is no slippage in the belt, it doesn't change anything. That is, both wheels move at the same speed and in the same direction. It's used if you need another shaft in a parallel position.

DRIVES & GEARING

With a twist in the belt you can see that there is more belt surface in contact with the wheel (like using the jockey) but more importantly, the wheels will rotate in opposite directions.

This drive shows a way to change the plane of rotation. The first shaft is turning at 90° to the second.

This drive incorporates gearing. The big wheel will rotate more slowly than the small wheel.

DRIVES & GEARING

Belts for friction drives come in many
shapes and sizes. You might use a
rubber band on a cardboard prototype
but the same principles are used in
industrial machinery. V-shaped belts
and pulley wheels give a bigger
frictional area and increased
efficiency. The belts in a workshop
pillar drill are usually like this.

V-belt — Pulley Wheel

You can also get polyurethane belts that can be joined by
heating the ends. Rubber belts can be bought from model
shops and washing machine spares shops.

Friction drives are usually simpler and therefore cheaper
than positive drives. However, there is likely to be some
slippage between the driven wheel and the driver. This
means that the driven wheel will rotate more slowly than it
is supposed to. If you need the two shafts to stay in perfect
synchronisation you need something more positive.

How to Swim No. 17 by Paul Spooner
The swimmer uses a spring drive belt
(the sort that is also used in model
steam engines) to connect the
main shaft to a pulley wheel
which makes the arms rotate. The
belt is twisted so that the arms
rotate at 90° to the main shaft.

DRIVES & GEARING

The mechanism for the dog's tail below is similar to the cam mechanism which lifts its jaw. In fact this is a simple friction drive. The plane of rotation is changed from the horizontal to the vertical with the aid of the friction between the two wooden discs. The lower disc rotates the upper one because it is positioned to one side of the upper disc's centre. It's like spinning a plate with your finger - nothing happens if you drag your finger across the centre, you have to spin at the outside.

More Positive Drives

Like friction drives, positive drives come in many different forms. Toothed belts (or timing belts) have teeth which engage with the notches on the pulley wheels.

Chain and sprocket systems work the same way except that the teeth are on the sprocket wheel. Chain systems can usually be adjusted to the right length by adding or removing links.

Get On Your Bike

Anyone who rides a bike (and uses the gears) should understand the relationship between speed and power. Gears make it easier to get up the hill but if you want to go at the same speed as you did on the flat you'll have to work harder at pedalling.

A difference in speed between two gears produces a change in the force transmitted.

That's nice.

When designing a machine you may find that you want some parts to move faster than others. Gearing is used to change the speed but it will also change the power delivered.

DRIVES & GEARING

So you don't get something for nothing. This notion should sound familiar. Does it remind you of levers? Good, because gear wheels are yet another form of lever.

The teeth on gear wheels are like a series of levers. As one set of teeth disengage another set engage so the leverage is applied continuously.

The design of gear teeth is quite a complex subject and beyond the scope of this book. However, it's quite possible to produce gearing mechanisms which are appropriate for the sort of machines we want to build without understanding all of the details. If you were making a machine which needed high precision gearing then you probably wouldn't make the gears yourself anyway.

When you look at the following examples try to think of ways you could make your own versions.

Here the spur gears are the same size, with the same number of teeth. This means the force and speed of motion is the same for both. This is called regulated motion. Notice that the direction of rotation is reversed.

In the more common situation, with wheels of different sizes, the smaller is called the pinion.

DRIVES & GEARING

In this diagram of a rack and pinion gear, the gear wheel meshes with a toothed rack which slides horizontally, This is another way to convert a rotary motion into a reciprocating (back and forth) motion.

In this diagram, the pinion drives the larger wheel. Because the larger wheel has twice as many teeth it must rotate at half the speed but it will do so with twice the force. If you imagine the bigger wheel as a bigger lever you can see it will have more force.

If you reversed the situation so that the big wheel was the input, or driving wheel, then you would say that the small wheel turns twice as fast but with half the force.

DRIVES & GEARING

It all depends what you want. You usually won't mind if the gearing gives you more power but if you want more speed **and** more power then you will have to make sure that you have extra speed at the input to start with.

These principles of gearing apply to friction drives as well. If you're using pulley wheels, the gear ratio comes from comparing the diameter of the wheels rather than the number of teeth.

In this diagram of a worm gear, the shaft has a screw thread on it which meshes with the toothed wheel. This is normally used to give a very slow but powerful force to the shaft of the toothed wheel.

DRIVES & GEARING

In this diagram of a bevel gear, the two wheels mesh at an angle of 45 degrees so that the plane of rotation is changed from horizontal to vertical (or vice versa).

Of course, it's not too easy to make your own bevel gears. The pin wheel gives similar (although less accurate and efficient) results and is much easier to make with simple tools. Unlike the friction discs in the Dog that we looked at previously, the pin wheel is a positive drive which means it doesn't rely on friction.

DRIVES & GEARING

Practical with Computers

To make your own pin wheels the first stage is to divide up two circles so that the pins on each wheel will mesh properly. If, for example, you decide on a 3:1 ratio you will draw two circles with a 3:1 ratio in their diameters. In the example shown opposite the diameters are 20mm and 60mm. Note that this is the diameter of the circle on which the pins will be positioned. This circle is known as the pitch circle. The actual size of the wheels will be slightly larger.

The pitch circles then have to be divided so that the number of pins are also the same ratio. This will ensure that the space between the pins is the same on both wheels and allow them to mesh correctly. In this example we have chosen to have 12 and 36 pins. To find out the angles that you have to divide the circle into, you divide 360^0 by the number of pins. $360/12 = 30^0$ and $360/36 = 10^{0.}$

Still Life by Matt Smith
The pin wheels in this piece serve two functions. A small pin wheel on the handle shaft drives a larger wheel. This slows down the action and changes the plane of rotation. As you will have guessed, the normally inanimate objects in this still life aren't still at all.

DRIVES & GEARING

It's hard to make pin wheels from cardboard so you might want to try some 6mm plywood for the wheels and some welding rod or nails (heads removed) for the pins.

10° GUIDES
WHEEL SIZE
60mm DIAMETER
DRILLING GUIDES

30° GUIDES
20mm DIAMETER

Templates for a pair of pin wheels

Using a lathe or pillar drill with a dividing head is the easiest way to make pin wheels but if you don't have access to such devices then you can draw drilling templates with a compass and protractor. However, it's much easier to produce accurate templates like this with a computer drawing program. Full instructions for doing this are on the CMT web site. (Address at the front of the book).

DR!VES & GEAR!NG

The Mill Girl and the Toff by Paul Spooner

The pin wheels in this piece are used in the same way as the Still Life. Here, the Mill Girl is so surprised by the presentation of a ring from her posh suitor that her eyes are popping out unwittingly. Meanwhile, their relatives are turning in their graves below. (One is made from expensive wood, the other is cheap)

Control

Control is a term which is used to describe the parts of a system which accept the input and instigate the output. Control can be as simple as a light switch and as complex as a computer program.

The parts of a light switch come between the physical action of pressing the switch and the connection of electricity to the light bulb.

Because it's so simple, a light switch would not normally be described as a control system, so here's another example where the input is more removed from the output.

A slot machine has to notice the insertion of a coin and begin it's operation. The machine may have to work for a specific period or it may need to complete a specific cycle of events. In both of these cases we have to deal with the fact that dropping a coin is an event which doesn't last long. The momentary action that can be registered when a coin passes through a slot has to be converted into something more substantial if we are going to provide some value for the money.

CONTROL

For a Limited Period Only

Some machines don't have an inherent cycle of events. They perform an action continuously and any point in the action is similar to any other. When you turn on a simple* laundromat tumble dryer you expect it to go around and around blasting hot air at the clothes. When the time is up the clothes may or may not be dry. To control this type of machine you need a timing mechanism which can count down a specified number of minutes. The timing mechanism is responsible for keeping the motor and heater operating until the specified time has expired. So a timer is another simple form of control mechanism.

*footnote: Some tumble dryers are more complex. They may have a reversible drum action which stops the clothes getting too tangled. They may also monitor the dampness of the clothes and decide when to stop. These are both control mechanisms - the first time-dependent and the second would require a sensor to monitor the humidity.

A Cycle

The Disgusting Spectacle lifts its hand and twists its finger in its nose. Then the hand goes back down again.

Although the Disgusting Spectacle is a very simple machine, it does have a specific start / stop position. The joke wouldn't work if the finger finished a previous cycle still up the nose.

If you used a timer it would have to be set accurately to match the length of time that the machine takes to complete one cycle. However, even if you did get the timing right it may be possible for the mechanics to get out of synch (synchronisation) with the timer. A better solution would be if the control system actually knew when the hand was in the end position.

When the control system knows what the mechanics are doing this is called feedback. In this case, a switch could be activated by some part of the machine when the arm is in the up position. The switch would then be a kind of sensor.

The Disgusting Spectacle by Tim Hunkin

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CONTROL

Thinking in Blocks

When machines start to get complicated it's often useful to group their operations together into a number of blocks. This makes it easier to think about the design without getting bogged down in too many details. So, at the simplest level the Disgusting Spectacle could be defined like this:

INPUT	CONTROL	OUTPUT
COIN IN	MOTOR SWITCH	MOTOR

It becomes more useful to design this way when there is some feedback in the control system because you can show the way the feedback will work by adding links between the blocks. Each block may contain another series of blocks, or they may define specific operations. In the Disgusting Spectacle there are sensors which tell the system what position the arm is in.

INPUT	CONTROL	OUTPUT
COIN IN	MOTOR SWITCH	MOTOR

SENSORS

This shows that the switching of the motor is dependent on a coin being put in and on the arm position. This is still a simplification. It could be expanded to show that there is one sensor for the up position and one for the down position.

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Cat Flap

You may think that this is starting to seem dangerously close to things like flowcharts and computer programming and you'd be right, but it's still relevant. It's all to do with problem solving.

Even though Tim Hunkin didn't draw a diagram like this when he designed the Disgusting Spectacle, (it's quite a simple machine and he already knew what he was doing), you should still find that designing like this can be useful.

Say you wanted to design a lockable cat flap from scratch. You're starting with a problem. How do I let a fairly stupid animal in and out of the house and not allow entry to all the other cats in the area?

Assuming you don't know anything about magnets and reed switches you can still approach the problem because you know what you want to happen. You can define the problem.

a) When our cat is at the door, unlock it.

b) When another cat is at the door, don't unlock it.

ACME CAT FLAPS

CLICK

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CONTROL

Now you can see that you need a way of identifying your cat from other cats while you're not around. So then it's a simple jump to attaching something to your cat that other cats don't have and building a sensor into the flap that will recognise the thing that the cat is wearing.

So now you have to go away and research sensors. After this you'll probably get to the usual solution; Your cat will wear a magnet which will operate a switch. Now you have another problem. What use is an electrical switch? You need something mechanical to activate the catch on the door.

So it goes on. You may even build a prototype and find that there are other local cats that wear magnets. So you may decide that you need a way to make the system unique to your cat.

The point is that any method that helps you solve problems is useful. In reality, you'll probably use a lot of different methods. Trial and error, drawing, block diagrams and research all have their place. With experience and practice you'll realise which is the most appropriate. If you don't have much experience then the final chapter should help.

A Latching Relay Circuit

When you drop a coin into a conventional (non-electronic) coin mechanism a switch is operated for a fraction of a second while the coin passes it. To operate a machine you need to turn this momentary action into something longer. One way of doing this is to use a relay in a latching circuit. A latching relay circuit can also be used when you want a push button start on a machine with a long sequence and you don't want people to have to hold the button for the whole time.

This circuit requires knowledge of basic electrical principles and you should only try it with a low voltage supply unless you really know what you are doing.

Before we look at the circuit, here's a description of how a relay works. A relay is an electro-magnetic switch. This means it uses the magnetism which is produced by passing an electric current through a coil, to operate switch contacts.

In the diagram you should be able to see that when the core is magnetized it will pull the armature towards it. The armature is a lever (surprise!) pivoting on the knife-edge. As it moves towards the core, it also pushes up the bottom contact into the top one.

CONTACTS

KNIFE EDGE

ARMATURE

CORE

COIL

CONTROL

When the coin is dropped the switch operates which then operates the relay. The relay holds itself on via it's own contacts (R_1). When the machine has finished the relay is released by the switch (Break). This switch also has to operate momentarily so that the circuit is reset ready for the next coin.

BASIC SCHEMATIC FOR A COIN-OP MACHINE

COIN

R_1

+ve

R

BREAK

-ve

R - RELAY   M - MOTOR

-ve

M

R_2

+ve

The break switch usually takes the form of a microswitch. Microswitches come in lots of shapes and sizes but they usually have a lever arm which operates the contacts inside the body of the switch. The diagram below shows a cam that could control the timing of the machine. The lever and roller microswitch has a small button which is pressed when the lever is pushed up.

The Improved Circuit

Operating the break switch with a cam often leads to a problem. If the machine stops dead the break switch may not reset. If this happens, the relay can't operate however many coins are dropped in. The following circuit overcomes this problem.

It works in basically the same way but making the break switch a changeover (toggle) switch makes the operation less critical. The power is held on by the relay or the break switch. When the break switch is first operated it provides the power and also releases the relay. As the machine stops the break switch returns to the starting state.

It's on the next page. Make sure you understand how the first one works before you try to figure it out.

CONTROL

IMPROVED CIRCUIT FOR A COIN-OP MACHINE

R - RELAY
no - Normally Open
nc - Normally Closed

Switched +ve

Output to motor

-ve

R

COIN

no

R1

no

nc

BREAK

R2

FROM
MACHINE

+ve

Input voltage

-ve

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The Checklist

Well, hopefully you now have a reasonable understanding of how mechanical systems work...

... but the proof will be in the pudding.

This chapter is intended to be a guide to one way of making automata. It does not, for instance, tell you how to operate a lathe. We have also avoided directing you towards particular materials. You may want to cut your cams from plywood on an electric table jigsaw; alternatively, your preference may be plasma-cutting steel plate. So if you need a particular craft skill, want to learn how to use certain machinery, or want to know more about working in particular materials there a lots of other books to help.

So now it's up to you to apply the principles to your own ideas. But remember that the simplest ideas are often the most effective. By keeping your design as simple as possible you are much more likely to succeed.

THE CHECKLIST

The Checklist

Most people don't like to follow lists while they are trying to make something. The checklist that follows should be read and absorbed so thoroughly that you don't have to refer to it while you are making.

Stage One

It's hard to make automata quickly so allow yourself plenty of time to complete each of the stages.

Observation

Collect ideas! Look closely at the way things move. Try to work out how the machines operate. Study how moving objects interact with other objects. Listen to the noises that they make.

From your observations, make detailed sketches and notes. Try to show how you think objects move. Keep all this information in your ideas book with other clippings from newspapers and magazines. Look out for pictures that inspire or amuse you. Think about how you can turn things you find into automata.

The more notes and sketches you make, the more ideas you will have. These ideas will generate more ideas. Making things generates ideas. The more you do, the easier it gets.

Discussion

It can be scary, but it's worth discussing your idea with other people. If you're worried about negative reactions you can approach it indirectly. For instance, rather than saying I'm going to make a piece of

automata and this is what it does, you could discuss the idea or joke that's behind it. By sharing your ideas with others you might discover a fresh perspective or an alternative solution to a problem. Good ideas can even come out of misunderstanding and accidents. The discussion process should also help you to clarify your ideas.

Inspiration

At this stage you should have gathered lots of material and given some time to thinking about and discussing your ideas. Now you should focus on a few of your best ideas. Is one particularly appealing? Or could you combine some of the best elements from a few different ones? If you're not inspired at this stage you can either go back to gathering and thinking or you could proceed in the hope that you will become inspired as you're working.

Drawing

Don't worry about how well you think you can draw. Use lots of diagrams to show how your idea will work. If you can illustrate how the mechanics will work you'll have a much better chance of actually making them work. Keep thinking about how the different pieces will be constructed and how they will fit together. A loose initial sketch is ok as a starting point but at this stage you should also be considering the engineering and construction that will be involved. You should also make up a list of the parts and different materials you will need.

THE CHECKLIST

Prototyping

Making a cardboard prototype is a fast way of visualizing and testing your idea. You may be able to check the mechanism by pinning flat pieces to a board. This is a good way to check things like lever pivot points and the throw of cranks and cams. You may want to consider making a complete card prototype before committing it to another material that's harder to modify. Beware of making prototypes from thin card. Big models may be too floppy to work properly. If you've ignored our previous advice and are making something complex then it might be a good idea to break the prototyping down into small sections.

Prototype Evaluation

It's important that your prototype works convincingly before you move on. Be wary of a prototype that nearly works - unless you want the finished piece to nearly work as well.

This is a good time to make adjustments and improvements. Look for ways to simplify the mechanics. See if you can make it with fewer parts. Do you need to do any new prototyping? Should you start from scratch?

Don't be afraid of making mistakes at this, or any other stage.

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THE CHECKLIST

Stage Two

Planning

Even the most experienced automata makers always take longer to make things than they think and say they will. However, it's still worth trying to plan your time. A schedule may turn out to be wildly inaccurate but unless you have one, you'll never know how wrong you can be. Always leave plenty of time for making adjustments to the mechanism and finishing. Consider the following: What materials will you use? What are the appropriate tools? How long will it take to make compared with the prototype?

Construction

It's a good idea to make the parts so that they can be easily taken apart and reassembled. Obviously it's no good if the parts are loose when they need to be tight but you will find the ability to dismantle very useful.

Another important point is to make parts so that they can be adjusted. For instance, give yourself a method to change the length of a linkage or move the pivot point of a lever.

Try to avoid using glue...

...you might want to dismantle things.

THE CHECKLIST

Test

So it's finished! Or is it? How long
and how vigorously you test your
design will depend on how long you
expect the machine to last and
what sort of abuse you expect it to
receive. You might begin
to realise that all you've
really done is made
another prototype.
Don't be disheartened
though - just remember the last time you experienced a
"real" machine breaking down.

Critical Evaluation

Does your machine work efficiently and achieve the aims
described by your original plans? If it does, then
congratulations.

If it doesn't, don't despair. You are not alone and you've
probably learned a lot. If you can see what went wrong and
where it went wrong you'll be better prepared for the next
one.

Everybody who makes automata makes mistakes. The trick is to learn from them.

The End

Making things move is a frustrating business even for people who are very good at it but if you enjoy it, don't stop.

Tock Tock Tock Tock Tick Tock Tock

Automata workshop

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Bibliography

Recommended Reading

This section should be entitled Possible Reading because there are very few useful books on automata or making mechanisms. A lot of the titles listed here are out of print. However, there are books that have parts which may be of interest. In general, you will probably find that secondhand book shops are more useful than the common high street variety.

Design and Technology
Books aimed at schools have sections on mechanisms, control and construction methods. For example, **Collins CDT - Technology**. Collins Educational. London. 1988. ISBN: 0 00327 434 9.

There are lots of books with "How Things Work" in the title. Obviously, the older editions have more mechanical devices. For example, **How Things Work** I (based on Wie Funktioniert das? Germany 1963). Granada. 1972. ISBN 0 586 08095 3 (1982).

Mechanics and Mechanisms
There are lots of very technical books which are full of vector diagrams and mathematics that are not terribly useful for this sort of work. You may find very old books which are more fun. For example, **The Mechanic's Friend** by Archibald Williams. Thomas Nelson. No date, no ISBN. I guess it was printed in the '50's. It has lots of practical information. You may never find a copy but I encourage you to look for similar things.

BIBLIOGRAPHY

There are also some reprints of old books on mechanisms. For example, originally printed in 1868 is **507 Mechanical Movements** by Henry T. Brown. Lindsay. 1984. ISBN: 0 91791 425 2 The publishers also print other books of interest (PO Box 538, Bradley IL 60915-0538 USA http://www.keynet.net/ ~ Lindsay/)

A book that is still available is **Basic Machines and How they Work**. Dover. 1971. ISBN: 0 48621 709 4. It's rather strange because it was produced by the Bureau of Navy Personnel (USA) so it has lots of diagrams featuring sailors doing mechanical things.

Paper Engineering
Paul Spooner's book of seven card cut-outs, **Spooner's Moving Animals**, also has Paul's view on the history of automata and his philosophy of 'Rough Automata'. Even if you don't make the cutouts, it's still worth buying for the words and pictures. Virgin (Abrams in the USA). 1986. ISBN: 0 86369 175 7.

Robots
There are build your own robot books that tend to cover electronics and servo motor technologies. There are also more general books which often have sections on the history of automata. For example, **Robots: Fact, Fiction + Prediction** by Jasia Reichardt. Thames and Hudson. 1978 ISBN: 0 50027 123 2.

Animatronics
This new book on the work of Jim Henson's Creature Shop shows the application of mechanics in the film industry. **No Strings Attached** by Matt Bacon. Virgin. 1997. ISBN: 1 85227 669 X.

BIBLIOGRAPHY

Mechanical Toys
There are quite a few of these but they tend to be aimed at collectors so they have very little mechanical detail. The most practical one I've found is **Mechanical Toys (How Old Toys Work)** by Athelstan & Kathleen Spilhaus. Robert Hale. 1989. ISBN: 0 70903 857 7

Automata
This is the most well known book on the history of automata. It's currently out of print but it shouldn't be impossible to find a copy. **Automata and Mechanical Toys by Mary Hillier**. Bloomsbury Books. 1976. ISBN: 1 87063 027 0 (1988).

Some of the most famous examples of old automata can still be seen operating. The Jaquet-Droz automata are housed in the Art and History Museum, Neuchatel, Switzerland. They also sell the book, **Androids - The Jaquet-Droz Automatons** by Roland Carrera, Roland. Scriptar SA. Lausanne. 1979. ISBN: 2 88012 018 7. This has the history of the machines as well as lots of detail on the restoration of The Musician.

Kinetic Art
Jean Tinguely was the most significant kinetic artist. A **Magic Stronger than Death** by Pontus Hulten and Jean Tinguely. Thames and Hudson. 1987. ISBN: 0 50027 489 4.

Other areas to check are Toys, Puppets and Crafts. If there is enough interest I'll put a longer version of this list on the web site.

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Cabaret Mechanical EduCat.

www.cabaret.co.uk   Nº· 1

Summer 2000

Inside

We have a large range of materials for teachers and students of design and technology.

Our new **Designing Automaton Kit** is a wonderful way to explore some of the basic mechanisms in Automata making without the use of any tools or glue!

We have a set of three **Posters** for classroom display and packs of postcards for student research portfolios.

Our large range of **Card Cutouts** and **Wooden Kits** offers an inexpensive way of building up classroom resources, and an excellent method for learning about mechanisms while constructing the kits.

Our book, **Cabaret Mechanical Movement** is aimed at students and teachers alike. It clearly explains basic mechanisms in a very appealing way as well encouraging an experiential but methodical approach to making automata.

The video **How to Make Automata** can be shown in two 20 minute sessions and is frequently used by teachers at the beginning of a project to inspire and to introduce some basic mechanisms in an entertaining way.

Cabaret Mechanical Theatre Education

Cabaret Mechanical Theatre

www.cabaret.co.uk

Cabaret Mechanical Theatre is a wonderful collection of over a hundred pieces of contemporary automata. We have pieces by Paul Spooner, Peter Markey, Keith Newstead, Tim Hunkin and Ron Fuller. We have recently relocated from Covent Garden to The Kursaal, a family entertainiment centre in Southend-On-Sea, Essex.

Many parents and teachers will already be familiar with our wide range of materials which are ideal for learning about mechanisms. Thousands of school children have visited our exhibition each year as we are specifically suited to Design and Technology work at Key Stages 2 & 3. Our exhibits offer inspiration and insight into simple mechanisms.

For the last four years we have run the 'Designing Automata' competitions for schools, along with workshops and Inset days for teachers.

Above: The Barecats. Designed by Paul Spooner and made by Matthew Smith.

Left: One of the finalists from our 1999 Schools competition - The Crocodile by David de Boo of Eggbuckland Vale Primary School, Devon.

Visits to Cabaret Mechanical Theatre

Cabaret Mechanical Theatre is now open at the Kursaal, Southend-on-Sea.
A visit to Cabaret Mechanical Theatre's exhibition at Southend-on-Sea is the perfect start to any project on designing moving toys.

The Kursaal
Eastern Esplanade
Southend-on-Sea
Essex
SS1 2WW

Admission prices:
Adults: £1.50
Children/Concessions: £1.00
Family Ticket: £3.95
Group Rate (Over 10 people): 20% Discount

For bookings please telephone:
01702 322322

Travelling Show for Schools

As not all schools will be able to visit our main exhibition and some may prefer to look at the exhibits for longer periods we have a Travelling Show for Schools. The exhibits consist of six boxed items and six pieces of hand-cranked automata.

The boxed items each have a power lead with a standard mains plug, therefore six electrical outlets will be required. They will sit on top of a table quite easily, and they are all operated by push-button. They have integral lights. There are film overlays on each box, describing some of the mechanisms in the piece and posing questions about its operation or construction.

The cost for hire will be £150 for the week, plus £85 for transport and £15 for insurance. Please note that these rates are exclusive of VAT.

To book the Travelling Show for Schools please contact Sarah Alexander:
Tel: 020 8516 3134 Fax: 020 8693 7644
e-mail: sarah@cabaret.co.uk

Lion Tamer with film overlay on front of case

Posters

A set of three posters for classroom display. The classic **Spaghetti Eater** poster (A2 size), a tongue-in-cheek poster describing how to **Make Your Own Manet's Olympia** (A3 size) by Paul Spooner, and **Moving Designs** (A2 size) a poster of children's designs as featured in Designing Magazine. £3-50 for a set of 3 posters.

CABARET MECHANICAL THEATRE

MAKE YOUR OWN MANET'S OLYMPIA

Postcards

A set of eight different postcards (designs may vary). These are useful for display and also for students to use in their research portfolios. £1.50 for a set of 8 postcards.

Cabaret Mechanical Theatre's Automaton Kit

Invent 100's of different automata - no glue or tools required

"Enormously creative and
engages the mind at any age"
- science material developers

O ur Automaton kit is the result of numerous requests (from teachers and makers) for a creative design tool which would allow for experimentation with simple mechanisms. After several years of research and workshop trials we believe this kit is one of the best ways to learn about mechanisms and invent new mechanical toys and automata.

- All parts are reusable
- No glue
- No tools
- Quick and easy to use
- Easy to add your own parts
- Cams cannot slip
- Fun
- Suitable for ages 7 and over

The Basic Kit £39.95

The box , (which also forms the base of the automata) contains all the parts necessary to make hundreds of different moving toys.

The cam shaft is easy to assemble and the cams can be used in any position. Instructions for making basic designs are included.

About the kit

The kit has been used successfully in many teaching workshops. All ages have taken part and learnt some of the basic principles of mechanics while making a moving toy.

"I was fortunate to have the opportunity to create a mechanical 'masterpiece' at your workshop at MIT and I can only begin to imagine the creations my students would construct using the kit."
- Workshop participant and teacher

Accessories

The basic box is designed to be used with these additional mechanisms, which can be purchased separately.

A. Crank Shaft £3-95.

B. Pulley Shaft £4-95.

C. Optional Panel 'B'*

*Not yet available.

Buy on-line at www.cabaret.co.uk

CARD CUT-OUTS

Surfing Dog £2-30 (H)

Flying Pig £2-30 (H)

Kissing Couple £1-50 (M)

Newspaper Man £2-10 (M)

Cat Watching Bird £1-30 (M)

Moving Heads £2-20 (M)
(makes 1 of 3 designs)

Dog £1-30 (E)

NEW!

Pirate £2-50 (M)

Cranky Man £2-50 (M)

Wave Machine £1-50 (M)

Scarecrow £1.20 (M)

Cut-outs and Books Difficulty Key: (E) - Easy (M) - Medium (H) - Hard

Twist and Shout £2-50 Ⓜ

Smuggling Dog £2-30 Ⓜ

Olympic Runner £1-50 Ⓜ

Chewing Sheep £1-20 Ⓔ

Snake in a Box £1-20 Ⓔ

Chewing Cow £1-20 Ⓔ

Mr Face £1-20 very Ⓔ

Hungry T-rex £1-25 Ⓜ

CARD CUT-OUTS

Printed card sheets to cut-out and assemble yourself. Hours of suffering and cut fingers. A good way to learn mechanical principles and impress your friends.
All 21 designs - £28.95

Anubis £2-50 Ⓗ

Cheetah £1-25 Ⓔ

Cut-outs and Books Difficulty Key: Ⓔ - **Easy** Ⓜ - **Medium** Ⓗ - **Hard**

WOODEN KITS

Kits available online at www.cabaret.co.uk

All the wooden kits are exclusive to CMT and you can
see most of them working at our web site. Most people
find these easier to make than the card kits because the
parts are already cut out. You can also have fun with
your own colour schemes. **All 8 designs** - **£125.00**

Cat Attack £16-50

Angry Cat £15-50

Flying Dragon £16-50

Copy Cats £15.50

Bone Ranger £16-50

more WOODEN KITS

Clickety-clack £16.50

Witch £15.50

Camel Simulator £23-50

BOOKS

Cabaret Mechanical Movement (£9-99) is packed with diagrams, information and useful tips on making your own automata. If you still don't know what a cam is, then this book is for you. 124 A5 pages with over 200 black and white illustrations.

Paper Automata (£4-95) by Rob Ives. Four designs - the Hopping Sheep, the Pecking Hen, the Flying Fish and the Motley Man. Just add scissors and glue. Ⓗ

Amazing Machines (£9-99) by Keith Good. Simple mechanical projects using low cost and readily available materials.

V I D E O S

Three VHS tapes which bring the wonderful world of CMT alive on your television. Add £2 for NTSC format (USA / Japan).

How to Make Automata (£12-99 42 mins) Learn with Keith Newstead the mechanisms and some of the methods involved in making automata.

Cabaret Mechanical Video (£14-99 43 mins) A video catalogue of the CMT collection. Includes interviews with the artists in their workshops, some of their other machines and mechanical explanations.

Made in Stithians (£9-99 34 mins) An amusing and inspiring portrait of Paul Spooner at work as he attempts to make a new machine in one day.

ORDERING INFORMATION

Prices include VAT but not post and packing. Overseas orders outside the E.C. are exempt from VAT (17.5%). Please phone, write, email or fax your order. (UK Schools: we will despatch and invoice if you fax or mail an official order).

Payment is accepted in UK Pounds only. We also accept Visa, Mastercard, Switch, AmEx, Diners and JCB.

Our phone number is 020 7379-7961. (International +44 20 7379-7961). 24-hour fax: 020 7497-5445 (Int. +44 20 7497-5445). E-mail: sales@cabaret.co.uk. On the fax, we need the card holder's signature and address, card number and expiry date. Please note that we will only charge credit cards when the goods are sent. Any orders which include unavailable items will be held until the complete order can be sent unless we are instructed otherwise.

Cabaret Mechanical Theatre
(mail order only)
Unit 15
95 Wilton Road
LONDON SW1V 1B2

http://www.cabaret.co.uk/

The machine, as seen at the end of the mechanical age

[by] K. G. Pontus Hultén

Author

Hultén, Pontus, 1924-2006

Date

1968

Publisher

The Museum of Modern Art: Distributed
by New York Graphic Society,
Greenwich, Conn.

Exhibition URL

www.moma.org/calendar/exhibitions/2776

The Museum of Modern Art

"The Machine"

🌀	*art*
🌀	*reconstruction*
💡	*invention*
🚗	*car*
📷	*camera*
▱	*reconstruction*
☀	*E.A.T.*

K. G. Pontus Hultén

The machine

as seen at the end of the mechanical age

The Museum of Modern Art, New York

works in the competition that they organized. The awards were generously donated by the American Foundation on Automation and Employment, Inc., first prize; the Mc Crory Corporation and the Trans-Lux Corporation, second prizes.

I am particularly indebted to Märta Sahlberg, the secretary of Moderna Museet. In addition to carrying the burden of her many regular duties, she has given unstintingly of her able assistance throughout. My colleagues at Moderna Museet have helped and shown patience.

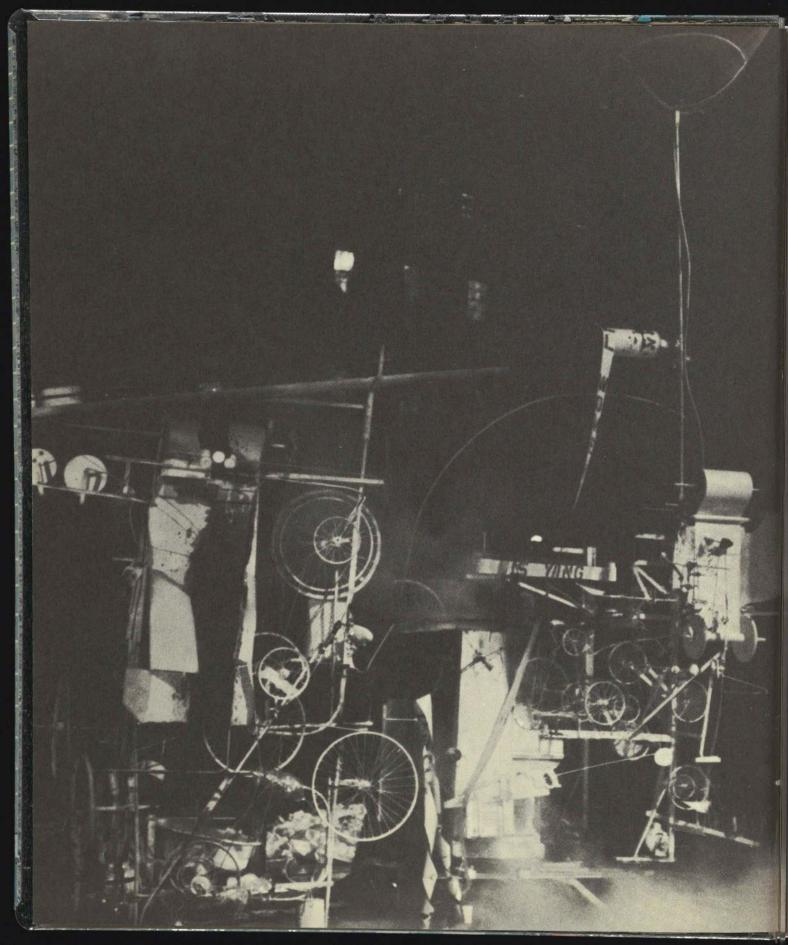My thanks also go to Emilio Bertonati, William Camfield, E. C. Goossen, Franz Meyer, Beaumont Newhall, Georgia O'Keeffe, George Riabov, Alan Solomon, and Kate T. Steinitz; and to the International Business Machines Corporation, which offered to make new models of Leonardo's flying machines for this occasion.

With respect to the catalogue, I wish to express my gratitude to Ulf Linde of the Royal Academy of Art, Stockholm, for allowing me to publish his important discoveries about Marcel Duchamp and alchemy, and to Billy Klüver for permission to include his essay on Jean Tinguely's *Homage to New York*.

Françoise Boas of the Department of Publications, The Museum of Modern Art, was helpful both in initial plans for this book and in coordinating arrangements for its printing in Sweden. Katja Birmann in Stockholm and Anne Dahlgren Hecht in New York assisted in research, and Barbro Sylwan of Moderna Museet carried out research in Paris during the days in May and June, 1968, when conditions were very difficult. Yvonne Frendel also aided in bibliographical research.

The book has been expertly edited by the Museum's Senior Editor, Helen M. Franc. She has added many important facts to it and has been untiring in her efforts to prepare the complicated manuscript for printing. In this task, and especially in compilation of the index, she was assisted by Christie Kaiser.

John Melin and Gösta Svensson of Stig Arbman AB, Malmö, designed this book and have worked on the project with great devotion for many months. They have been assisted by a number of their colleagues.

This exhibition could not, of course, have been realized without the generosity of the artists, collectors, museums, and galleries who kindly made loans available. On behalf of the Trustees of The Museum of Modern Art, the University of St. Thomas, and the San Francisco Museum of Art, I wish to express thanks to all the lenders listed here, as well as to several who preferred to remain anonymous.

K. G. P. H.
Stockholm,
September 1968

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Bonino Gallery, New York; Leo Castelli Gallery, New York; Cordier & Ekstrom, Inc., New York; Roman Norbert Ketterer, Campione d'Italia (Lugano); Marlborough-Gerson Gallery, Inc., New York; Galerie Nierendorf, Berlin; Galleria Schwarz, Milan; Howard Wise Gallery, New York.

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Foreword and Acknowledgments

This exhibition and its catalogue make no attempt to provide an illustrated history of the machine through the ages. It is a collection of comments on technology by artists of the Western world. During many centuries, there seem to be few such statements; at other times, they have been quite numerous. Generally speaking, our own century has been more productive than any other in this respect. This may be because we are now far enough removed in time from the early stages in the development of the mechanical age to be able to see more clearly some of the problems involved and to realize some of the implications, both for individuals and for society. It may also be because intensive exploitation of the earth's resources by a rapidly expanding technology has created a situation that is now altering our way of life if not actually endangering our survival.

Moreover, technology today is undergoing a critical transition. We are surrounded by the outward manifestations of the culmination of the mechanical age. Yet, at the same time, the mechanical machine — which can most easily be defined as an imitation of our muscles — is losing its dominating position among the tools of mankind; while electronic and chemical devices — which imitate the processes of the brain and the nervous system — are becoming increasingly important.

The works in this exhibition have been selected because they seem to demonstrate a particular interest by artists in aspects of the world of machines. They have been ranged in roughly chronological order. Some of the earlier items have been included for their relevance as precedents for manifestations today, or to illustrate attitudes of their time toward technology.

Two kinds of functional mechanisms — the automobile and the camera — are represented by a few examples, again with no intention of summarizing the complicated evolution that either of them has undergone. The car and the camera (like motorcycles, boats, aircraft, and guns) are machines with which many people feel a strong emotional tie, as intimate extensions of their bodies. The car was chosen both because it is probably the most typical machine of the twentieth century and because it is almost certainly the mechanical device that most affects our private, everyday lives. As such, it not only fulfils a practical purpose but has become a symbol, a focus for our fantasies, our hopes, and our fears. The camera, together with some photographs and films, was chosen because it is a picture-making, mechano-chemical device, which has provided the basis for much of our way of seeing and is therefore particularly appropriate in an art exhibition. (A special film program has also been organized to complement the showing of THE MACHINE in New York.)

It seemed essential that an exhibition concerned with artists' attitudes to technology should have the greatest possible openness toward the future, the more so since many artists today are working in close collaboration with engineers. For this reason, Experiments in Art and Technology (E.A.T.) agreed to arrange a competition and kindly made several of the entries available for inclusion in the exhibition at the Museum. The others will simultaneously be on view elsewhere.

The plans for this exhibition were begun several years ago; the first letters discussing it were exchanged in 1965. When René d'Harnoncourt, the late Director of The Museum of Modern Art, asked me whether I should like to organize an exhibition on kinetic art for his institution, I proposed instead to concentrate on a part of that subject and expand it. Although there had recently been several shows of kinetic art, surprisingly little had been done with regard to the theme treated here. Mr. d'Harnoncourt and his successor, Bates Lowry, continued to show interest throughout and made themselves available to help in many ways.

I wish to express my gratitude for the assistance and cooperation I have received from many people and institutions in the preparation of this exhibition and its catalogue. In discussing initial plans, Troels Andersen, Copenhagen, Ronald Hunt, Newcastle upon Tyne, and Kasper König, New York, made important suggestions. William A. M. Burden, a Trustee of the Museum of Modern Art, placed his knowledge of automobiles at our disposal; he, David Rockefeller, Chairman of the Board, and Monroe Wheeler, Counsellor to the Board of Trustees, were instrumental in helping to obtain some especially difficult loans.

The first staff member of the Museum to work on the exhibition was Jennifer Licht, Associate Curator of the Department of Painting and Sculpture. She has been a key person ever since, making essential contributions at all levels; without her devoted interest, this project could never have been fulfilled. She was assisted by Jean-Edith Weiffenbach, who gave admirable care and attention to organizing the voluminous correspondence involved. Among the many other members of the Museum's staff who helped in various ways, I should like to thank especially William S. Rubin and Sarah Weiner, of the Department of Painting and Sculpture; Eila Kokkinen of the Department of Drawings and Prints; and Bernard Karpel and Inga Forslund of the Library. Wilder Green, Director of Exhibitions, has helped to solve several important practical problems, particularly with relation to the installation of the exhibition. Dorothy H. Dudley, assisted by Betty Burnham, was responsible for the complicated arrangements required to assemble in one place such a large number of disparate objects. Margareta Akermark and Adrienne Mancia of the Department of Film undertook the selection and organization of the film program.

Francis Mason, Billy Klüver, Amy Martin, and the staff of Experiments in Art and Technology were of unfailing help in connection with providing information about the

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Introduction

This exhibition is dedicated to the mechanical machine, the great creator and destroyer, at a difficult moment in its life when, for the first time, its reign is threatened by other tools.

It would be childish to believe that the greatest geniuses of our time have amused themselves with illusory games and have wilfully disguised their thought. However bizarre their great games may seem, they have made apparent in fiery characters the major myth in which is written the fourfold tragedy of our age: the Gordian knot of the clash among mechanization, terror, eroticism, and religion or anti-religion.

These are the portentous alarm signals that they are sending out to us, from the heights of their observatories erected atop high towers, at the heart of the modern tempest.

— *Michel Carrouges,* Les Machines célibataires

Upon this faith in Art as the organic heart quality of the scientific frame of things, I base a belief that we must look to the artist brain, of all brains, to grasp the significance to society of this thing we call the Machine . . .

— *Frank Lloyd Wright,* address to the Chicago Arts and Crafts Society, March 6, 1901

A machine generally means to us something with a practical purpose, a device that substitutes for or extends man's own forces. The word itself has the same root as "might." We take the machine's usefulness for granted; yesterday's new invention, no matter how amazing, quickly becomes the commonplace of today.

This limited concept, however, is relatively recent. Historically, machines have often been regarded as toys, or as agents of magic, marvel, and fantasy. For philosophers, they have served as symbols and metaphors. Since the beginning of the mechanical age and the time of the Industrial Revolution, some have looked to machines to bring about progress toward utopia; others have feared them as the enemies of humanistic values, leading only to destruction. Most of these contradictory ideas persist, in one form or another, in the twentieth century and find their reflection in art.

Machines may be loosely defined as tools composed of several parts working together. They have a twofold ancestry. On the one hand, they develop from the practical experience of laborers or artisans seeking new ways to ease their work or perfect their skills. Their other line of descent leads from abstract thought and pure science to applied science and invention.

The Greeks, heirs of the technics of earlier civilizations, were the first to develop machines. All the simpler mechanical principles were known to them, such as the wheel and axle, the wedge, the lever, the gear, the screw, and the pulley; and they had a great knowledge of hydraulics and pneumatics. They applied these principles as occasion required but never adapted them for mass production. (The producing machine, in fact, appeared relatively late in the history of technology.) Siegfried Giedion has gone so far as to state: "In a practical direction, the sole systematic application of the ancients' physical knowledge was to warfare."

It was the Greeks who first systematically investigated natural forces and formulated scientific laws. Freed from the domination of a priestly class, which in earlier Mesopotamian and Mediterranean cultures had guarded for itself all learning, they joyfully pursued knowledge for its own sake, irrespective of its practical uses. The same word, *techné,* meant both art and technics. In spite of their love of the beautiful and the practical, the Greeks nevertheless ranked artists and technicians far below philosophers in their hierarchy.

Aristotle took a wider view. He, or his pupil Strato, wrote the *Mechanica,* the oldest engineering textbook. Its opening passage well illustrates the Greeks' attitude to applying their knowledge to nature: "Nature often operates contrary to human expediency; for she always follows the same course without deviation; whereas human expediency is always changing. When, therefore, we have to do something contrary to nature, the difficulty of it causes perplexity, and art has to be called to our aid." Further on in the book, there is a good example of the

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ars considered themselves the heirs of the ancients, with a responsibility for the revival of lost knowledge. This is apparent in the words of Roger Bacon (1214—1294), who in his *Epistola de secretis operibus* set these goals for engineers:

"We can construct for navigation machines without oarsmen, so that the largest ships on rivers and seas will be moved by a single man ... We can construct vehicles, which, although without horses, will move with incredible speed. We can also construct flying machines of such a kind that a man sitting in the middle of the machine turns a motor to activate artificial wings that beat the air like a bird in flight. Also a machine of small dimensions to raise and lower enormous weights, of unequalled usefulness in emergency ... We can also make machines to move through the sea and the watercourses, even to the bottom, without danger ... These machines were constructed in ancient times and they have certainly been achieved in our time, except, perhaps, the flying machine, which I have not seen and I do not know any person who has seen it, but I know an expert who has perfected the means of making one. And it is possible to build such things almost without limit, for example bridges across rivers without cords or supports and unheard of mechanisms and engines."

Bacon was far in advance of his time, both in such visions and in his defense of empirical investigation and free experimentation. It was not universities like Oxford, however, which were to provide the training ground for the engineers of the Renaissance, but the courts of Europe, and particularly those of the Italian princes. Besides summoning into their service the most expert men they could find to stimulate manufacture, build towns, canals, palaces, churches, and fortifications, arrange spectacles, and advance military techniques, they also formed great libraries, ordered translations from the classics, and commissioned the writing and publishing of new treatises.

Leonardo da Vinci, therefore, was very much the product of his age and environment, though his genius and the universality of his thinking have led to his being regarded as unique. What sets him apart is the systematic manner in which he attacked so many branches of knowledge. His may be considered the first modern mind. Leonardo's endless curiosity led him, though largely self-taught, to assimilate most of the scientific and mathematical learning of his day; his imagination led him to attack problems that others had not even discovered; and his intuition led him to many conclusions beyond those then susceptible of proof. He was the first to realize that mathematics can provide the basis for scientific statement and proof: "There is no certainty in science where one of the mathematical sciences cannot be applied." Leonardo incessantly made experiments to establish facts that could be verified numerically.

His direct observations, his formulation of theoretical principles, his scientific studies, and his art, all had a common goal: the better understanding of life and nature. When the body of his work is taken together, Leonardo should be considered primarily as a scientist and engineer rather than as an artist. His technical drawings, however, are far freer than those of his contemporaries; they are neither working drawings nor scientific illustrations. His projects are related to him in an exceptionally personal way. This is especially true of his studies for the invention that most preoccupied him — a flying machine.

With the Renaissance, two currents essential for an advanced technology flowed together. Theoretical scientists were more disposed to check their theories by experimentation; craftsmen and engineers were eager to grasp abstract principles that might explain and help to expand their techniques. The key to further scientific development lay in a more exact and advanced mathematics and its application to mechanics. With Galileo and others, giant strides in this direction were made during the sixteenth and seventeenth centuries.

Mathematical methods could deal only with quantitative, not qualitative, phenomena. During the seventeenth century, such methods were nevertheless applied to all human experience. Only the properties of matter that could be objectively measured — its dimensions, mass, and motion — were regarded as real. Those that depended on the subjective senses — color, taste, and odor — were considered to possess no external reality. In his *Discourse on Method* (1637), Descartes attempted to reconcile deductions from mathematics with the concept of a universe created by God. A fixed amount of matter and motion had been put into the world at the time of the Creation by the Deity, who once having decided upon the mechanical laws that should govern all nature did not interfere with the self-running machine that He had made. This idea corresponded well both with the theological concepts of the Calvinists and with the current political doctrine of absolute sovereignty.

In the Cartesian system, all material things — human beings, animals, plants, and inorganic nature — are machines, ruled by the same inexorable laws, and so susceptible of analysis by the quantitative methods of mathematics. In *Human Robots in Myth and Science*, John Cohen has pointed out the irony of the fact that the highly rational Descartes should have come upon his idea of the universal laws of mathematics in a dream, which he had on November 10, 1619, "a day at least as memorable as the day the Battle of Hastings was fought." This concept would ultimately lead to the modern computing machine. Descartes' contemporary Pascal (1623—1662) did in fact invent a calculating machine that could add and subtract. Somewhat later, Leibniz (1646—1716), whom Norbert Wiener has suggested as "the patron saint of cybernetics," expanded these ideas and constructed an even better calculator. Leibniz foresaw a machine that would be able to reason so well that it could ultimately formulate a complete mathematical system of the universe.

Descartes had faith that there was no situation in

Greek ideal of collaborating with the forces of nature for man's benefit. The author observes that in keeping to their course in an unfavorable wind, the sailors and the steersman adjust the sails and turn the rudder, so that: "The wind then bears the ship along, while the rudder turns the wind into a favoring breeze, counteracting it and serving as a lever against the sea. The sailors also at the same time contend with the wind by leaning their weight in the opposite direction."

During the Hellenistic period, Alexandria supplanted Athens as intellectual capital of the ancient world. Throughout the Hellenistic empire, technology advanced rapidly as newly discovered principles were put into practice in enormous engineering projects and the construction of great cities.

The Romans, intensely practical in their outlook, were little concerned with the advancement of theoretical science but made extensive use of what was already known, applying this knowledge in warfare, navigation, and gigantic building projects, and systematizing it in treatises. Vitruvius' *De architectura* is the only important work on civil engineering to have survived. Its tenth and last book is entirely devoted to mechanics. Among the few devices it describes that make use of any form of power other than human or animal labor is a geared mill, with a paddle wheel turned by water.

The ancients not only formulated the laws of mechanics and put them to practical use but also devised ingenious machines whose only purpose was to serve as marvels. In the Golden Age, the Greeks produced elaborate stage effects; for example, a hoist enabled an actor representing a deity to appear from on high at a climactic moment and resolve all difficulties — the *deus ex machina*. During the Hellenistic period, mechanical marvels proliferated. We read of temple doors operated by warm air that opened automatically when a fire was lit on the altar and closed again as the flames died down. Philo of Byzantium (third century B. C.) describes in his *Pneumatics* siphons that allow vessels to empty and refill themselves automatically, or pour wine and water alternately. There are also washbasins worked by counterweights and pulleys, which make a bronze hand extend a pumice stone to the user, disappear when he takes it, and reappear to receive it again after enough water has flowed out of a spout to allow him to wash his hands. A major part of a treatise on mechanics by Hero of Alexandria (c. 100 A.D.) is devoted to similar gadgets. Some of the wonder-working apparatus was put at the service of the priesthood of Alexandria, for example a coin-in-the-slot device combined with a holy-water dispenser that flowed only when money was put into it. Many of the mechanisms described in these books had great potentialities for practical purposes, such as a water wheel, a wind vane, and even a rudimentary steam engine. But the steps to develop these from toys to power machines was never taken in antiquity. The uses that Hero suggests for his "ball rotated by steam" are to blow on a fire, to cause small statuettes to dance, a mechanical bird to sing, or a Triton to sound his horn!

Automata were the most famous of the wonder-working mechanisms of the ancient world. They exerted a powerful spell on the imagination, and even if they were meant to be amusing rather than awe-inspiring, they could cause a certain uneasy speculation. A fascination with automata was inherited by the Byzantines. There is a detailed sixth-century description of an elaborate water clock, housed in a tower at Gaza, in which the hours were marked by small statues of Hercules performing his twelve labors. The Arabs, besides developing instruments such as the astrolabe, concentrated much of their technological interest on intricate automata. They transmitted the tradition of mechanical vessels and water clocks to Western Europe; the ambassador of Haroun al-Raschid presented a clock with automatic figures to Charlemagne. No actual Arabic automata have survived, and the manuscripts that describe and illustrate them deal only with their performance and outer appearance, so we know little of how their mechanisms worked.

The early Middle Ages did not offer a favorable climate for the development of science and technology. Scholarly speculation was diverted from abstract science to theology, and respect for authority inhibited experimentation. There was also a tendency to equate scientific learning (which continued to flourish chiefly among the Arabs and Jews) with heathenism, if not actually with black magic. Hard manual labor was regarded as man's destiny after his expulsion from Eden, and even as an attribute of holiness, so there was no incentive for developing labor-saving devices.

The Middle Ages nevertheless gradually made increasing use of animal-, water-, and wind-power. The water wheel and windmill helped to raise the production of food beyond the mere subsistence level. Between the thirteenth and fifteenth centuries, water power gradually came into use also for saw mills, grind stones, forges, pumps for draining mines, and blast furnaces. In Northern Europe, especially, there were important advances in sailing: the stern-post and rigging that made it possible to tack closer into the wind. These and the magnetic compass extended the scope of navigation and trade.

Technological advances were also made by artisans in many crafts such as masonry, metalwork, and weaving. As the guild system grew, crafts became more specialized. Towns increased in size and number. The life of the community began to be regulated by mechanical clocks, which appeared in the latter part of the thirteenth century and were perfected in the fourteenth. Set high in public places, they replaced the variable liturgical hours with a secular division of the day into twenty-four equal hours. Besides this utilitarian function, many of them, for example the famous clock at Strasbourg Cathedral, continued the marvelous pageantry tradition of the earlier water clocks. Clockwork mechanisms were also adapted for elaborate spectacles at festivals.

With the rise of the universities, there was a steady advance in the scholarly tradition. The medieval schol-

ster that Mary Shelley created in *Frankenstein* (1817) was another symbol of the fear that the machine, instead of being man's slave, might become his master and destroyer.

In the nineteenth century, it was finally realized that a perpetual machine was impossible; machines would always require great labor to keep them functioning. The tremendous increase in manufacture also demanded that more material be constantly sought to keep the machines fed. A reckless exploitation of the earth's natural resources resulted. Whole geographical areas came to be regarded as nothing but providers of raw materials — sources that could be used and depleted. This attitude was transferred from materials to whole continents and classes of people. Karl Marx defined the situation in a speech he gave in London in 1856:

"Machinery, gifted with the wonderful power of shortening and fructifying human labor, we behold starving and overworking it. The new-fangled sources of wealth, by some weird spell, are turned into sources of want. The victories of art seem bought by the loss of character. At the same pace that mankind masters nature, man seems to become enslaved to other men or to his own infamy."

By the mid-century, opinions about machines and their potentialities were completely confused. Optimism and belief in progress existed side by side with great despair. Which opinion one held depended largely on one's position in society. For the entrepreneur, laissez-faire policies meant a golden age. For the working classes, freedom was extremely restricted; they bore all the hardships of exploitation and received almost no benefits of production.

In literature, the most optimistic exponent of progress and of technology's unlimited possibilities was Jules Verne. Science opened up all paths before his heroes — solitary geniuses who with the aid of miraculous inventions could force any environment to yield to their will. A completely opposite view is that of Samuel Butler in *Erewhon* (1872). Three chapters of this book, which describes an imaginary state ("nowhere" spelled backwards), deal with its technology. Butler foresaw a human race that had become parasites of the machine, making man "an affectionate machine-tickling aphid." In a reversal of La Mettrie's concept of man as machine, Butler depicts machines as human beings with intelligence and initiative. He argues that animals and vegetables have taken millions of years to evolve to their present state, whereas machines so far have had only a few hundred years in which to develop.

It may be surprising to read what Norbert Wiener had to say in his pioneering book, *Cybernetics* (1948), about Butler's vision, with reference to the computer:

"I have said that this new development has unbounded possibilities for good and for evil. For one thing, it makes the metaphorical dominance of the machines, as imagined by Samuel Butler, a most immediate and non-

metaphorical problem. It gives the human race a new and most effective collection of mechanical slaves to perform its labor. Such mechanical labor has most of the economic properties of slave labor, although, unlike slave labor, it does not involve the direct demoralizing effects of human cruelty. However, any labor that accepts the conditions of competition with slave labor, accepts the conditions of slave labor, and is essentially slave labor. The key word of this statement is *competition*. It may very well be a good thing for humanity to have the machine remove from it the need of menial and disagreeable tasks; or it may not. I do not know."

The phenomenal changes that technology and the Industrial Revolution brought about in man's social and political life were frequently treated in literature but largely bypassed in art. The few pictures that deal with any aspect of the subject tend to be illustrative or anecdotal. When new industrial themes appear, they are usually rendered purely pictorially, as in Turner's *Rain, Steam and Speed*, Monet's *Gare St. Lazare*, or Seurat's somewhat later drawings of industrial cityscapes. Even paintings by artists who were concerned with the worker's situation — Courbet, Millet, Pissarro — make no profound statement on his social condition. As Klingender has observed: "The alliance that had grown up in the later part of the eighteenth century between science and art was based on a common foundation of optimism. When political economy abandoned the humanist standpoint for a sophistical defence of property, the link between science and art was broken."

From the Renaissance to the late eighteenth century, science and art had interacted, and great scientific discoveries had their counterparts in art. The interplay between art and science may be regarded as one of the most significant factors within any culture. In ancient Greece, both arose from a common inspiration; there was no more opposition between nature and the application of natural laws in technics than there was between technics and art. Man was perceived as a part of nature, a microcosm of the universe, or the highest species in an ascending scale of beings. Everything could be brought within the sphere of human comprehension, and the world regarded as an ordered unit. But as scientific knowledge became more complex, rational, and secular, it also became more specialized. Man's idea of the world could no longer be contained within a unifying framework but became increasingly fragmented. The specialization of science also meant that it became more professionalized and directed toward utilitarian ends, and so further removed from the humanities. (Since Einstein, however, modern scientists have once again been thinking in terms of unified fields.) The more man sought to bend nature to his will by force, the more alienated from it he become. In Giedion's words: "In the nineteenth century the path of science and art diverge: the connection between methods of thinking and methods of feeling was broken."

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human life, no problem facing mankind, that could not be solved if one applied the infallible, all-encompassing laws of mathematics. There is a story that he constructed a mechanical woman, Francine, on mathematical principles. During a sea voyage, a prying fellow-traveler opened his luggage, discovered Francine, and brought her to the captain, who threw her overboard as a product of black magic. In any event, Descartes declared that the mechanistic theory of the human body should not "appear at all strange to those who are acquainted with the variety of movements performed by the different automata, or moving machines, fabricated by human industry. . . . Such persons will look upon this body as a machine made by the hands of God, which is incomparably better arranged, and adequate to movements more admirable than in any machine of human invention." The body of a human being was differentiated from that of all other created beings, however, because God had placed within it a rational soul. Through this, man alone could participate in the incommensurable, spiritual world.

This dualism of man's nature was transformed into a mechanical monism in the following century by Julien La Mettrie, whose book *Man as Machine* (*L'Homme machine,* 1747/8) greatly shocked his contemporaries. Believing that men and animals alike function as machines, he drew an analogy from time-pieces, which at this period were being much refined: "Man is to the ape, to the most intelligent of animals, as Huygens' planetary clock is to a watch of Leroy." La Mettrie allowed no place for such factors as intuition, imagination, creativity, or biological time — hence, no place even for death. (His adversaries thought it a great victory when he proved his materialistic soullessness by dying of overeating.) In spite of his limited outlook, he dominated intellectual discussion during the third quarter of the century and greatly influenced the thought of such men as the encyclopedist Diderot.

The development of clockwork and other kinds of precision instruments, together with the concept of the universe as a great time-machine that had been wound up and set in motion by God, led to the making of increasingly intricate automata. No longer merely toys or marvels, they corresponded with the philosophical preoccupations of the time. As symbols or as works of art, however, they are quite uninteresting. They imitate the faces and hands of human beings and are dressed in real clothing. The essential factor — the mechanism — is completely concealed. Thus the problem of creating an integrated image remained unsolved.

The paradox within the Age of Reason is well illustrated in the case of Jacques Vaucanson. Unable to earn his living in the sciences, he created an elaborate artificial duck and two musician automata, which immediately attracted the interest of the public and the learned men of the day. Because of his knowledge of machinery, he was made the government's Inspector of the Silk Manufactures. He proposed many advanced schemes and made many inventions, including a machine for fabricating patterned materials, but he met with constant checks in his career; and none of his ingenious devices won him nearly the fame he had attained with his automata. Vaucanson scornfully declared that though an inventor "would never be regarded as an artist by the Academicians but would be despised as a mere maker of machines, these gentlemen would be more humble if they were to reflect that this solitary mechanic has done more to assure man's well-being than have all the geometricians and physicians in their entire Society!"

This is a perfect expression of the idea, prevalent at the time, that advances in science and invention were necessarily beneficial to mankind. The rationalist thinkers were all firm believers in progress. They were convinced of man's perfectibility. New medical discoveries would make him not only healthier but wiser than before, and improved education would complete the process. Enlightened opinion would lead to improvement in the institutions by which men are governed, thus creating still more enlightened opinion; and so mankind must continually advance. Voltaire, for example, in 1756 declared his belief that: "reason and industry will progress more and more, that useful arts will be improved, that the evils which have afflicted men and prejudices which are not their least scourge, will gradually disappear among all who govern nations."

At the beginning of the nineteenth century, the initiative in technological advance passed to England. It was there that the great drama of the Industrial Revolution, which dominated the century and completely changed society, was principally played out. Steam power was now used extensively for mining, transport, and manufacture. Factories multiplied, and new industrial towns grew up. In America, the shortage of skilled labor for the task of settling an entire continent stimulated the invention af labor-saving devices and the use of power machinery.

Not everyone observed these changes with the same optimistic belief in progress that had characterized the Enlightenment. There was great disillusionment when, after the French Revolution, hopes for better governments were frustrated by the establishment of new tyrannies. Workers, finding their livelihood threatened by accelerated mechanization, were rioting, breaking the machines, and being put down by force. Living conditions in mining regions were dreadful. In the towns, as people left the countryside to find work in factories, population grew at an unprecedented rate, and slums spread quickly. A mood of despondency replaced the earlier hopes for science and technology. As Klingender has pointed out in *Art and the Industrial Revolution:* "Milton's Satan was readily accepted as the symbol of the new scientific forces in society, because he embodied intelligence, ingenuity and science in the cosmic struggle and was at the same time a symbol of man's self-destruction and inevitable doom." The mon-

before, he transmitted his ideas about machines to the Dadaists, who had previously taken no particular interest in the subject.

The positions of the Dadaists toward machines varied widely. In Cologne, Ernst and Baargeld felt ambiguously about them. When they used mechanical forms, it was usually for poetic purposes, and in an ironic way, to express a subjective attitude. They intermingled the rationality of machine forms with irrationality to create paradox and confusion. In Hanover, Schwitters, though more philosophical and detached, took a related position. Heartfield and Grosz, in Berlin, soon abandoned their initial Dadaist skepticism for an almost unlimited admiration for Constructivism and "machine art."

The concepts of machine art held by the New York Dadaists and by the Russian Constructivists working in Leningrad in the years following the Revolution were extremely different. Tatlin was eager to put his art at the service of the Revolution. He saw the future of the new society in the development of science and industry, and he wanted his art to be a spontaneous expression of that new society's dynamism and to reflect the spirit of machine culture. His greatest work, the model for a Monument for the Third International (1920), was a fusion in one structure of architecture and sculpture with motorized elements. Though Tatlin had a clear, strong vision, he avoided giving it a definite theoretical formulation. To someone seeking to change society, yet unable to foretell what the eventual result of the revolution may be, the exact way in which changes are brought about is not essential. What is important is respect for the properties of the materials used, and the logical structure that arises out of them, which determine the content of both art and society. In the aircraft — one-man gliders — that Tatlin began to construct late in the 'twenties, his intention was to combine his artistic concept of truth to materials with his ideas about utility and society. He concluded that "the most aesthetic forms are the most economical"; but his complex thought goes far beyond this statement and involves, as he said, "art going out into technology" — the fusion of art and life.

Tatlin's influence was strongly felt in theater, film, architecture, furniture design, posters, and typography. (A newspaper clipping of about 1927, reproduced in a book by the Italian Futurist Depero, reports that the Charleston had been banned in the Soviet Union in favor a a new "machine dance" inspired by mechanical movements!) The philosophy of the "culture of the machine" survived in debased form under Stalin, to give birth to representations of happy factory workers and tractor operators.

Tatlin's chief followers in Germany were Lissitzky and Moholy-Nagy, who founded a Constructivist group in Berlin in 1922. His influence was further spread through Moholy's teaching at the Bauhaus, which built its program mainly on Tatlin's ideas. The atmosphere of the Bauhaus reflected a generally optimistic point of view toward machines, but the original ideas soon became a diffused belief in the possibilities that technology offered for artistic use, and the desirability of applying principles of good design to manufactured articles.

A similarly optimistic attitude prevailed in France at about the same time. Léger, who in the late 'teens had manifested an interest in the impressive plastic forms of artillery, came under the influence of the more theoretically minded founders of machine aesthetics, Le Corbusier and Ozenfant. The Purists, like the Russian Constructivists, wished to unify all the arts in the service of society and recognized that modern society must be increasingly dependent on technology. But it was the clarity, precision, and elegance of machine forms that the Purists — unlike the Constructivists — particularly admired. This admiration was accompanied by a glorification of the role of the technician in society: "Engineers are healthy, virile, active and useful, moral and happy," Le Corbusier wrote in *La Peinture moderne* (1925). In this book, he and Ozenfant, like new Darwins, postulated a law of mechanical, rather than natural, selection. It "establishes that objects tend toward a type which is determined by the evolution of forms between the ideal of maximum utility and the demand of economical production, which conforms inexorably to the law of nature." Having very little actual knowledge of how machines worked or what they could do, Le Corbusier and Ozenfant based their mechanolatry on a confusion between functionalism and the mere absence of unnecessary decoration. In *Theory and Design in the First Machine Age,* Reyner Banham has shown the weakness of the Purists in founding their machine aesthetics on pictorial values — qualities which, as he points out, "are conditional attributes of engineering, and to postulate them as necessary consequences of machine production was to give a false picture of the engineer's methods and intentions." What interests engineers is mechanical tolerance, not finish; a high degree of polish nearly always has to be achieved by hand. Most objects reproduced in the publications on machine aesthetics were expensive, specialized, handmade articles, such as the wheel of a Bugatti car. The theory nevertheless had worldwide influence.

The worship of machines that prevailed in the late 'teens and early 'twenties had changed into an opposite attitude by the 'thirties. Confidence in man and in man's capacity to be the rational builder of a better world, which had been the basis for Constructivism, was replaced by a different kind of faith — in "psychic automatism" and the powers lying hidden beneath the surface of an individual's seeming rationality. This new faith had been proclaimed in Breton's Surrealist Manifesto of 1924. When the Surrealists concerned themselves with machines, it was to depict them as the enemies of nature or to explore their erotic implications.

The growing rebellion against those who wished to

Faith in progress was debased into faith in production, and sentiment deteriorated into sentimentality.

William Morris, a man of strong social conscience, followed Ruskin in avoiding the problems of mechanization chiefly by dissociating himself from it. In his romantic belief, only renunciation of industrial production and a return to the guild system of medieval craftsmen could lead to the recovery of lost humanistic values. What Morris opposed was also that mass production had so fragmented manufacture into isolated processes that it robbed the worker of any identification with what he produced; he lost his sense of pride and purpose, and naturally design suffered as well.

But machines could produce many more articles far more cheaply than could individual artisans, and the growing middle class was increasingly eager for manufactured goods. Enthusiastically embracing the utilitarian, public opinion relegated Art to a small, isolated area. Art was placed on a pedestal, respectfully venerated, and consequently quite misunderstood. Architects continued to be trained in academies of the "fine arts"; it was in polytechnical institutes that engineers learned to use the new materials. What the engineer built might be admired for its ingenuity and utility but had nothing to do with popular concepts of Beauty. It was nevertheless in building that new methods and materials first won acceptance, even on aesthetic grounds.

By the year 2000, technology will undoubtedly have made such advances that our environment will be as different from that of today as our present world differs from ancient Egypt. What role will art play in this change? Human life shares with art the qualities of being a unique, continuous, and unrepeatable experience. Clearly, if we believe in either life or art, we must assume complete domination over machines, subject them to our will, and direct them so that they may serve life in the most efficient way — taking as our criterion the totality of human life on this planet.

In planning for such a world, and in helping to bring it into being, artists are more important than politicians, and even than technicians. But, of course, it is not artists in whom we ordinarily most place our confidence.

The story of how artists of this century have looked upon and interpreted machines is highly dramatic. Their attitudes have ranged from deepest pessimism and despair to devotion and even idolatry. It should be noted that such extreme positions have been taken by artists who are among the most significant of our time.

For the Futurists, technology represented the dynamic means by which they hoped to overcome the stagnant traditions of Italy — a country in which the glories of the past encumbered youth more perhaps than anywhere else. Before Marinetti decided on "Futurism" as the name for the movement he launched in 1909, he first considered "electricism" and then "dynamism." In spite of their enthusiasm for machines and their hopes that through them the whole world could be changed, the Futurists' view of them remained rather superficial. They inherited from the Impressionists the tendency to look principally at the appearance of things. It was the polished metals, bright colors, and noise of machines that the Futurists admired, and the heady sensations of speed and power that they enjoyed. But for the most part (with the great exception of Boccioni, as in his *States of Mind* series), they never tried to reach a deeper understanding of what machines represented in people's emotional lives; nor, in spite of their activism, did they ever clearly analyze what machines were bringing about in terms of social change.

The Cubists held very divided attitudes toward the mechanical world. Their use in collages of manufactured materials such as newspapers, nails, or twine was of course important in breaking down old concepts of what was acceptable in making works of art, and was to be carried much further by the Dadaists and Surrealists. But Picasso has never made any statement whatsoever about machines in his art, nor did Braque and Gris show any interest in the subject. On the other hand, Duchamp-Villon's *Large Horse* was an ambitious attempt to infuse into traditional sculpture the kind of energy found in engines; and Léger translated the impressive forms of machines into several beautiful paintings.

Duchamp, who began as the youngest of the Cubists, soon developed his concepts into a philosophical and metaphysical system — something which the Cubists in general did not attempt. His meditations on movement and machines led him into previously unexplored regions. He rapidly passed through his preliminary interest in the outward aspect of machines to create a new kind of visual metaphor. This enabled him to express complex ideas that involved, among other things, non-Euclidean geometry, chemistry, and alchemy. The machine-eroticism that we find in his work is a theme first elaborated in the writings of Poe, Villiers de l'Isle Adam, Roussel, and others, as an ironic blend of eroticism and sadism with ideas about magic powers and the superman. In *Surmâle* (1902), Jarry wrote: "In this age when metal and mechanics are all-powerful, man, in order to survive, must become stronger than the machine, just as he has to become stronger than the beasts." By using the machine and technological language in a new way to express his most complex thought, Duchamp did indeed dominate the power of the mechanical world. Many of his early discoveries about machines he passed on to Picabia, Man Ray, and Ribemont-Dessaignes, who developed them in their own works.

During the early years of the war, Duchamp and Picabia brought their initial ideas about machines from Paris to New York. Stimulated still further by the developed mechanization of the American environment, Picabia for a number of years concentrated most of his work on machinist subjects. In 1919, on a visit to Zurich, where Dada had officially been born three years

Catalogue of the Exhibition

All the objects other than comparative material repro-
duced in this catalogue are included in the exhibition, un-
less listed as lost or destroyed or represented by re-
constructions, with the exception of those illustrated on
the following pages: 15—16 (represented by facsimiles
and models), 20, 21, 26, 35, 93, 98, 111, 143, 144—145.
Works listed on the following pages have been lent for
the New York showing only: 18, 36, 57, 60, 61, 62, 63, 60,
70, 73, 75, 77, 78, 82, 87, 89, 95, 100, 103 above, 105
above, 113 (New York and Houston only), 127, 138, 141,
149, 153, 180, 187 right.
In dimensions, height precedes width. Drawings are on
paper unless otherwise noted.

@   *art*

@   *reconstruction*

☀   *invention*

🚗   *car*

📷   *camera*

▱   *reconstruction*

💡   *E.A.T.*

rule society by the blind application of technological principles is illustrated in Huxley's *Brave New World* (1932). This pictures a future in which children, produced in a scientifically controlled bottling factory, will be educated as to their position in the social order by broadcast maxims, drilled into them while they sleep.

The economic crisis of 1929 and the unemployment that it created intensified pessimism. Some of the most direct comments about machines can be found in films. The first Frankenstein film was made in 1931. The sentiments of the time find their keynote in Chaplin's *Modern Times* and *The Dictator*. In his final speech in the latter film, the little man says: "Machinery that gives abundance has left us in want. Our knowledge has made us cynical; our cleverness, hard and unkind. We think too much and feel too little. More than machinery we need humanity. . . ."

Chaplin did not share the popular belief that the introduction of sound was a great advance for the film. Some of the disillusionment that artists of the 'thirties felt about machines came in part from the experience of the sound film. There was a decline in quality, as attention was diverted from cinematic values to the novelty of spectacular musical comedies or plays translated into movies. Films now cost much more to make, and they became increasingly commercialized as producers sought to please mass audiences to ensure the return of their investment. It was a great disappointment to recognize that a technological achievement could have such a negative effect on an artistic medium.

The late 'thirties and the years of World War II are of no great interest for the theme of this exhibition. Dada had been born out of opposition to the culture that had fostered the first World War. No comparable movement now arose, for the obvious reason that for many years most of the artists had already been opposing Fascism in Italy, Germany, Spain and elsewhere. Military action, when it came, seemed a continuation of this struggle. On the other hand, the manner in which the war was conducted had little in common with the artists' earlier position; it was only a further exemplification of the principle of might against might. This resulted in a general sense of frustration that lasted long after the war itself was over.

The bombs dropped on Hiroshima and Nagasaki were the most terrible shock that the world has ever received. Fear and horror sapped the faith in technology and the confidence in rational behavior that might have been expected to follow a long period of destruction. When Vasarely and other artists began to develop a new Constructivism, it took its name from the earlier movement but focused largely on formal problems. Most of what Tatlin and his followers had tried to achieve in relating technology to life was lost.

This lack of content was felt by artists like Munari and Tinguely. From the mid-'fifties on, they have devoted themselves to an attempt to establish better relations with technology. Standing astonished and enchanted amid a world of machines, these artists are determined not to allow themselves to be duped by them. Their art expresses an optimistic view toward man, the creator of machines, rather than toward technology as such. They lead us to believe that in the future we may be able to achieve other, more worthy relations with machines. They have shown that while different aspects of our relations to machines may conflict, they are not necessarily contradictory. Not technology, but our misuse of it, is to blame for our present predicament.

The Pop artists have also taken a step toward finding a way out of this alienation. They have tried once again to relate mass products to human will and show that they have been created by the human intellect, and are related to the human body.

For someone living today, there are obvious advantages in expressing oneself through art. There is great freedom of expression. Without much hindrance from forces external to oneself, one can construct models for the world as one would like it to be. At the same time, the artist is obliged to assume total responsibility for what he does; no one else can be blamed for his successes or failures. John McHale has described the present situation: "The future of art seems no longer to lie with the creation of enduring masterpieces, but with defining alternative cultural strategies. But in destroying the formal divisions between art forms, and in their casual moves from one expressive medium to another, individual artists do continue to demonstrate new attitudes towards art and life. As art and non art become more interchangeable, . . . the artist defines art less through any intrinsic value of the art object than by furnishing new concepts of life style."

Perhaps what is most frightening is the notion that modern technology has an evolution of its own, which is uncontrollable and independent of human will. Many economists and technicians speak as though they were merely explaining inevitable processes — deterministic laws, analogous to natural laws, that govern the development of technology. In their fatalistic view, the products and consequences of technology and mass production simply grow by themselves, like a landscape.

There is no doubt that if we are not to become the victims of what we ourselves produce, we must quickly attain a society based on other values than buying and selling. The amount of data involved in managing society at all levels is increasing at terrific speed, as is the quantity of justifications for decisions. The decisions that will shape our society in the future will have to be arrived at, developed, and carried out through technology. But they must be based on the same criteria of respect and appreciation for human capacities, freedom, and responsibility that prevail in art.

To paraphrase what Tristan Tzara said about Dada: "No one can escape from the machine. Only the machine can enable you to escape from destiny."
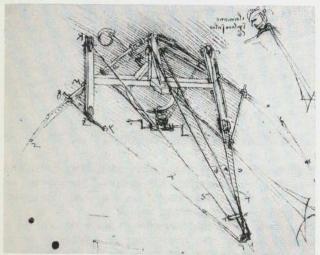
2 Wing mechanism

and the parachute. For the most part, his flying machines are far less rational than his other studies and inventions, lacking the clear insight that generally characterizes his research. Most of his aircraft were ornithopters. Although his apparatus were very heavy, he does not seem to have been concerned with their weight but attached such unessential gear as retractable undercarriage mechanisms to the already ponderous machines.
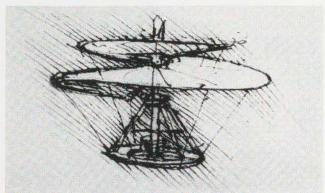
"A bird is an instrument working according to mathematical law, which ... is within the power of man to reproduce ...." All Leonardo's early ornithopters were based on a misunderstanding of the up-and-down movement of birds' wings when they fly. It was not until the invention of the camera that the movement of birds in flight could be accurately studied (see page 36).

It was only rather late in life that Leonardo began to study the principles of the glider, which would seem to have provided the obvious solution to overcoming the problem of weight. His point of departure was then not observation of the flight of birds but of the movements of a falling piece of paper.

3 Flying machine in which a man lying prone uses arms and legs to flap the wings

In a booklet on Leonardo's aeronautics, Charles H. Gibbs-Smith recently suggested that the reason he came so late to the construction of a glider was that "a factor beyond the passion for truth and enquiry was at work, a factor which indeed hindered and twisted his investigations; for, inextricably interwoven with his desire to impartially investigate the problems of flight, was his powerful symbolic interest in the romantic idea of flight."[1] The explanation for the relative irrationality of Leonardo's flying machines in comparison with his other technological works is probably that they have to do with the strongest emotional complex of his character. His mind had an enormously strong escape mechanism; he was obsessed with going away, with the flow of water, and he left most of his works unfinished. Thus, in his flight studies, two main streams of Leonardo's mind cross: the wish to understand the world, and the wish to find a new world. It is futile to try to decide whether, in designing his flying apparatus, he acted as scientist or as artist.

4 Helicopter

Leonardo's drawings for helicopters are an indication of his fascination with the spiral form, which he often finds and isolates in nature. He made a model for a helicopter, possibly based on a toy, known since the early fourteenth century, that could be sent spinning into the air by pulling a cord wound around its shaft.

Leonardo's studies had no direct influence on the development of aviation. His work remained unknown until his manuscripts were published late in the nineteenth century. (From some of his drawings and descriptions, Roberto A. Guatelli has constructed models for the International Business Machines Corporation.)

5 Parachute

"If a man have a tent made of linen of which the apertures have all been stopped up ... he will be able to throw himself down from any great height without sustaining any injury."

Leonardo da Vinci

Italian, 1452—1519

☀ *Drawings for
flying apparatus*
c. 1485—1490

From Manuscript B,
Bibliothèque de l'Institut
de France, Paris:
1, folio 80 recto; 3, folio 75
recto; 4, folio 83 verso

From the Codex Atlanticus,
Biblioteca Ambrosiana,
Milan:
2, folio 313 recto (a);
5, folio 381 verso (a)

*1 Flying machine in which the
operator stands upright*

In Leonardo da Vinci's surviving notebooks, there are more than 35,000 words and over 500 sketches that deal with the nature of flight and with flying machines. Many aspects of his approach to reality go into these studies: his penetrating observation of nature, his love of theoretical knowledge and, above all, of mechanics, which he termed "the paradise of the mechanical sciences because by means of it one comes to the fruit of mathematics"; his sense for the empirical testing of theory through experimentation; his creative fantasy as an artist. The studies also reveal his emotional obsession with the idea of freedom and escape.

Leonardo concerned himself with many kinds of aeronautical devices: the ornithopter or craft with wings controlled by a man's feet and arms (in one design, a rudder is operated by a head harness), the helicopter,

15

Giovanni Battista Bracelli
Italian, active 1624—1649

◎ *Knife-Grinders* (Plate 28 from *Bizzarie di varie figure . . .*). 1624. Etching, c. $3^1/_4 \times 4^1/_2''$ (composition) Library of Congress, Washington, D.C. (Rosenwald Collection)

The history of machine-people and machine-animals goes back to the earliest reports on mechanical devices. Automata were a principal manifestation of technology among the Arabs, who transmitted and developed the tradition from antiquity to the Middle Ages. Functioning automata were shown as great marvels at the courts and exhibited at medieval fairs throughout Europe.

Representations of machines as people occur in the seventeenth, eighteenth, and nineteenth centuries. Like the automata themselves, they exerted a fascination not only as marvels, but because they posed the riddle: What was the distinction between man, and inanimate beings that moved and functioned like man? There was something intriguing in the sacrilegious idea that these were men created, not by God, but by man himself, and thus without souls.

The philosophical problem was set forth by Descartes, who in his *Discourse on Method* drew a distinction between non-spatial mind and space-occupying matter:

By body I understand all that can be terminated by a certain figure; that can be comprised in a certain place . . . that can be moved in different ways, not indeed of itself, but by something foreign to it by which it is touched . . . for the power of self-motion, as likewise that of perceiving and thinking, I held as by no means pertaining to the nature of body; on the contrary, I was somewhat astonished to find such faculties existing in some bodies.[2]

The paradox man-as-machine/machine-as-man, which continued to be discussed in the ensuing centuries, has in our own time been of particular interest to the Dadaists and Surrealists. It is worth noting that Tristan Tzara wrote an introductory essay for the publication, in 1963, of a facsimile of Bracelli's *Bizzarie* in the Rosenwald Collection — the only complete copy known.[3] Bracelli was a Florentine, who dedicated the original edition of forty-five etchings that composed the *Bizzarie* to Pietro Medici. In the plate reproduced here, one knife-grinder is the whetstone, the other the bell that summons customers.

Petitot, a native of Lyons, was active in Parma, where in 1771 he published a suite of ten engraved plates entitled *Mascarade à la Grecque*. They represent persons in various walks of life — a shepherd and shepherdess, a grenadier, a monk, and so forth. Their costumes, as in this drawing, are composed of objects, but although the *Two Engravers* is obviously related to the series, the subject does not appear among the printed plates.

18

School of Albrecht Dürer

German, first quarter of 16th century

◎ *The Triumphal Procession of Maximilian I:*
Plate 95, *The Austrian War*. Original blocks, before 1526;
reprint, Vienna, 1883—1884. Woodcut, $18^1/_4 \times 23^3/_4''$
(sheet). The Metropolitan Museum of Art, New York
(Harris Brisbane Dick Fund, 1932)

This woodcut is one of several in *The Triumphal Procession* of Maximilian I that depict curious man-driven vehicles, with the Emperor's various battles represented on their sides. The cogwheel mechanism turned by cranks that foot soldiers operate is, of course, completely impractical. A chariot powered in this way could at most advance a few yards along a straight line, very slowly — but that would be its greatest feat.

The elaborate woodcuts for *The Triumphal Procession* were ordered by Maximilian I in 1512. The project engaged the efforts of a large number of the most famous artists of Nuremberg, Augsburg, and the Danube region, including Albrecht Dürer, whose share in the actual execution was minimal. (The block shown is attributed to Hans Springinklee or Hans Burckmeier.) The program, conceived by the Emperor himself, was worked out in detail by his secretary. The work, interrupted by Maximilian's death in 1519, was published seven years later by the Archduke Ferdinand.

Clockwork mechanisms were highly developed in Germany during the Middle Ages, and Dürer himself had sufficent knowledge of engineering to produce a treatise on fortifications in 1527. The machinery here, however, is meant merely to impress by displaying technological lore, as humanistic learning is paraded in the allegorical figure of Charity riding on the front of the car and the classical river god reclining in the landscape.

17

Jacques Vaucanson
French, 1709—1782
☀ *Duck*, 1733—1734
Automaton (photograph
of lost original, or
imitation, in ruined state)
Musée du Conservatoire National
des Arts et Métiers, Paris

Hubert François Gravelot
French, 1699—1773
Vaucanson's Automata. 1738
(from Jacques Vaucanson,
"*Le Mécanisme du Flûteur automate . . .*)
Engraving

The eighteenth century saw both a great advance in the actual construction of automata and a heightened interest in philosophical discussions regarding the mechanistic nature of man. Today, we might be fascinated by the ingenuity of such perfectly functioning figures as those created by Vaucanson in France and Jacquet-Droz in Switzerland, and certainly we should be interested in the workings of the machinery that enabled artificial musicians to play, penmen to write or draw, and a duck seem to eat and digest his food. The intricate machinery, however, was always completely concealed. To contemporary spectators, the great attraction was the perfect imitation of living beings and

the speculations about the nature of life to which such verisimilitude gave rise.

Vaucanson's duck is perhaps the most famous automaton that has ever existed. Already as a child, Vaucanson had built angels with wings that moved and priests that functioned automatically. Influenced by Descartes and by contemporary philosophers of the Enlightenment, Vaucanson wanted to construct moving anatomical figures (*anatomies mouvantes*), which could be used by physicians and surgeons to demonstrate bodily operations. Arriving in Paris at the age of twenty-six, he lacked money for these experiments and decided instead to produce "some machines that could excite

20

Les graveurs à la grec

Ennemond Alexandre Petitot. French, 1727—1801

◎ *Masquerade Costumes: Two Engravers (Les Graveurs à la grec).* c. 1771
Ink and color wash, $7^{5}/_{8} \times 5''$ (sheet). The Metropolitan Museum of Art, New York
(The Elisha Whittelsey Fund, 1960)

How rotary movement can be transformed into reciprocating motion.
6¹/₄" high×15" long×4³/₄" deep

Kristofer Polhem. Swedish, 1661—1751

☼ *Letters from Mechanical Alphabet.* Wood, 1772—1779
(originals c. 1700)
Tekniska Museet, Stockholm

Polhem, "the Archimedes of the North," was a scholar, inventor, engineer, and industrialist. A great patriot, he wished to encourage Swedish metallurgy so that the iron, copper, silver, and other metals mined in northern Sweden would not have to be exported to be made into useful objects. Around 1700, to facilitate his teaching, he constructed a series of small wooden models that could serve as an "alphabet" of the basic mechanical functions. The alphabet included in all about eighty "letters," each demonstrating, as his pupil Cronstedt said, "the simple movement that is contained in a machine." This seems to have been the first attempt to treat mechanics in such a methodical manner and teach the basic laws of movement in the abstract, without reference to specific practical applications.

Polhem established a factory in which he introduced the principles of mass production. He is quoted as having said: "There is great need of machines and appliances which will, in one way or another, diminish the amount or intensity of manual work. This result can most adequately be achieved by the substitution of water power for handwork . . ."[6] Waterfalls provided the main source of power, which had to be transported from the river to the factory by mechanical means. The various kinds of transmission catalogued in Pohlem's alpha-

How a disc fastened to a vertical axis transforms its rotary movement to the pumping of an attached arm. 13³/₈" high×15" long×9⁷/₈" deep

bet were put into practice. In one famous case, power was transported across very rough country to a mine almost two miles distant from the waterfall.

How rotary movement transforms the action of 4 straight rods (2 vertical, 2 horizontal) into reciprocating motion.
20³/₄" high×17³/₄" long×11¹/₂" deep

Three ways to fit and steer a rod making a straight reversible movement. 7¹/₂" high×26" long×5¹/₂" deep

Pierre Jacquet-Droz. Swiss, 1721—1790

☀ *Young Writer.* c. 1770

Automaton. Musée d'Art et d'Histoire, Neuchâtel

public curiosity." In 1738, he presented before the Académie Royale des Sciences three automata — a drummer, a flute-player, and the duck, which were described in a prospectus as: "an artificial Duck made of gilded copper which drinks, eats, quacks, splashes about on the water, and digests his food like a living Duck."[4] They met with an immediate and enormous success — not only among the public but among savants as well. Voltaire in his rhymed *Discourse on the Nature of Man* hailed Vaucanson as the "rival of Prometheus." He was cited in similar terms by Julien La Mettrie, who was born in the same year as Vaucanson and who in *L'Homme machine* wrote the first systematic statement of the mechanistic theory of man's mind.

The duck was exhibited with great acclaim throughout Europe, fell into ruins, was repaired, lost, and rediscovered, and is last recorded in the 1860s. A series of photographs, including the one reproduced here, was found some years ago in Paris. Some scholars believe they represent the ruins of Vaucanson's duck, while others believe them to be of another automaton made

in imitation of it by a German clockmaker, who spent years in repairing the original duck and then constructed another of his own.[5]

The most perfectly developed writing automaton in the world is that made in 1770 by Pierre Jacquet-Droz. The Arabs were the first to construct mechanical penmen, but no automata actually capable of writing had been made before this. When the mechanism is started, the boy dips his pen in the inkwell, shakes it twice, places his hand at the top of the page, and pauses. As the lever is pressed again, he begins to write, slowly and carefully, distinguishing in his characters between light and heavy strokes.

The mechanism that produces the movement of the writer, and of two companion pieces, a young boy drawing and a young lady playing the organ, is a system of levers concealed in the backs of the figures. What Vaucanson wanted the world to admire in his automata was mysterious artificial beings. To contemporary spectators, the little mechanical writer must have seemed almost intolerably perfect. He must have inspired feelings of curiosity, admiration, and probably also paralyzing inferiority. The young scholar embodies the idea of perfection — an ideal man, who never makes an error, never gets in a bad humor, and never revolts.

In this book, Restif de la Bretonne gives a detailed description of the "Flying Man," Victorin, and his adventures in the antipodes. Victorin's experiments in flight are motivated by his love for the beautiful Christine. He longs to take her away and place her in a nest on the "Inaccessible Mountain," far from her parents. Aided by a friend, he studies the flight of birds and decides that if he can make two enormous wings and fasten them to his body at various points, he might be able to fly. As his arms are not strong enough to propel such gigantic wings, this must be done by his thighs. When Victorin is aloft, he flies horizontally.

This account, however fanciful, is not entirely dissimilar to the idea of Leonardo's ornithopter. Like Leonardo and Tatlin (see pages 16 and 144—145), Restif de la Bretonne felt a strong urge to escape from society. In his youth, he was involved in a scandal for which he served time in prison.

Restif was apprenticed to a printer in Auxerre and later went to Paris, where he set up his own printing establishment and produced more than two hundred volumes. Most of them are licentious, filled with accurate descriptions of the underworld of his day, and draw liberally on episodes in his own life.

24

Filippo Morghen
Italian, born 1730, active 1757—1800

◎ *Bishop John Wilkins Taking off for the Moon on His Imaginary Voyage* (title page of *Raccolta delle cose più notabili . . .*, 3rd edition). c. 1784—1785
Etching, $12^3/_4 \times 19''$ (irregular; sheet). The Metropolitan Museum of Art, New York
(Harris Brisbane Dick Fund, 1932)

John Wilkins (1614—1672) was a prominent Puritan clergyman who tried to reconcile Copernicus' theories with Calvinist theology. He was also interested in promoting industry and navigation by the application of scientific principles and experimented with a number of technical devices, including wagons powered by sails like those on a windmill. In 1660, he was a founding member of the Royal Society.

Wilkins' *Discovery of a New World*, published in 1638, attempted to prove that there was another world of animate, rational creatures on the moon. Noting that astronomers had observed on the moon mountains and what looked like seas, he wrote: ". . . we may guess in the general that there are some inhabitants on that Plannet: for why else did Providence Furnish that place with all such Conveniences of Habitation?"[7]

The erudite Wilkins became the hero to whom were attributed a series of fantastic adventures etched by Filippo Morghen. Morghen, who is one of the earliest science-fiction artists, always kept his conceptions within the almost possible. He provided for Bishop Wilkins' transport the newest type of hydrogen balloon, invented about 1784, attaching it to the winged box and adding it over the text of the frontispiece of earlier editions.[8] In another plate, Morghen showed a "boat that has the wings of an enormous bird for sails" — a nice variant of Wilkins' invention of a sail-powered wagon.

◎ *Bird Boat* (from *Raccolta delle cose più notabili . . .*, 2nd edition). 1766—1768
Etching, $10^7/_8 \times 15^1/_4''$. The Metropolitan Museum of Art, New York (The Elisha Whittelsey Fund, 1949)

Nicolas-Joseph Cugnot. French, 1735—1804

🚗 *Steam Locomotive* ("the oldest self-propelled vehicle in the world"). 1770—1771
Musée du Conservatoire National des Arts et Métiers, Paris

Cugnot constructed the first locomotive cars. Little is known about his very first locomotive, except that it was meant to drag or carry artillery pieces and was built on a three-wheeled carriage, with a combustion steam-power plant operating over its single front wheel. After it was demonstrated in the presence of French army officers, in 1770 Cugnot was commissioned to construct a second, larger machine on similar principles. The car was intended to run at a speed of about a mile and a half per hour and pull four to five tons.

There seems to have been no real test run for this second locomotive, and it was never used. An astonishing lack of curiosity among the people responsible for the funds prevented it from being tried. This may have been for fear of so powerful a machine, or simply because of political events. During the Revolution, Cugnot left for Belgium but returned under Napoleon's Consulate and taught at the Arsenal. It was from there that his locomotive, ignored for thirty years, was removed in 1800 to the Conservatoire, where it still stands.

The principle of steam locomotion had nevertheless been solved, although the development of the locomotive came to a dead end in France with Cugnot's pioneering effort. The initiative passed to England, where in 1784 James Watt had taken out a patent for a steam-driven road carriage, and where in 1804 Richard Trevithick's locomotive on rails successfully completed a nine-mile run (see page 49).

26

Unknown British artist
19th century
☼ *The Great Nassau Balloon with Parachute*
("The Great Nassau Balloon as it appeared from The Royal Vauxhall Gardens, Accompanied by the Parachute, in which the late unfortunate Mr. Cocking made his fatal descent, July 24th, 1837")
Hand-colored lithograph, $12^3/_4 \times 7^3/_4''$
The Metropolitan Museum of Art, New York (gift of Paul Bird, Jr., 1962)

Charles Green, one of the nineteenth-century's best-known astronauts, aspired to make the first transatlantic balloon flight. His most record-breaking journey, however, was in 1836, when he covered the 480 miles from London to the Duchy of Nassau in Germany. His craft was thereafter called the "Nassau" and made a number of spectacular ascents under royal patronage.

The "Nassau" was used for one of the strangest experiments in the history of technology, recorded in this lithograph and described in the anonymous *Book of Inventions:*

Cocking had joined Green on many of his flights, and he imagined that he presented a most ingenious parachute to the world, in the form of an umbrella, turned inside out. Cocking had observed that the cloth of an umbrella always turns this way when the umbrella falls from a height. But he did not realize that this is only a consequence of air resistance, and that the convex surface of the umbrella favors the gliding of air, so that the object can more easily follow the direction of weight. Deaf to all warnings, Cocking was firmly determined to try his parachute, and Green was imprudent enough to permit this lunacy.

... the two gentlemen took off from Vauxhall in London. The luckless parachute was fastened beneath the gondola of the balloon, and Cocking took his place in a basket under it. When they had reached some 3,000 feet, Green warned him once more, but Cocking cut the rope that tied him to the balloon, and ... plunging through the air ... covered the whole distance, close to 3,400 feet, in a minute and a half. People rushed to the place where the parachute had fallen, and found the poor man absolutely crushed.[9]

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Drawing the Retorts at the Great Gas Light Establishment, Brick Lane.

London. Pub.ᵈ by Sir Richᵈ Phillips & Cᵒ Feb.ʸ 1. 1821.

W. Read Sculpᵗ

W. Read. British, active 1821—1837

⊚ *Drawing the Retorts at the Great Gas Light Establishment, Brick Lane* (frontispiece from Colin Mackenzie, *One Thousand Experiments in Chemistry.* London, Sir Richard Phillips & Co.). 1821 Aquatint, $8^3/_8 \times 10^1/_4''$ (sheet). Science and Technology Division, The New York Public Library, Astor, Lenox and Tilden Foundations

The curiously innocent attitude that artists of the early nineteenth century had toward the technical world is dramatically shown in this print. Conditions in the gaslight establishment must have been truly infernal, yet Read seems not to have been bothered in the least by the plight of the people working there. He has, in fact, made them look supernaturally strong and healthy, easily capable of dominating the monster machines that they serve. He seems also to have been impressed by the awesomely picturesque effects of the scene he rendered. The billowing smoke and fiery glow within the structure are like manmade parallels to the clouds and moon glimpsed through the grating.

Read's imagination did not encompass the actual human implications in the scene. He was apparently as oblivious of these as Turner was when he rushed to record in his sketchbook the spectacular burning of the Houses of Parliament in 1834.

Note. In the Ladies Vehicle the Steam is made with a strong infusion of Gunpowder Tea   (LOCOMOTION.)   For an explanation of the Machinery see the next Number of the Edinburg Review.

Robert Seymour ("Shortshanks"). British, 1798—1836

◎ *Locomotion.* n.d. Hand-colored etching, $8^{1}/_{4} \times 13^{3}/_{4}''$
The Metropolitan Museum of Art, New York (gift of Paul Bird, Jr., 1962)

Most artists of the period of the Industrial Revolution were naive in their treatment of machines. The relatively few images that deal with machinery or industry are anecdotal, sentimental, or satirical. While poets or novelists were deploring the spoliation of rural England, and the slavery and degradation that mechanization was bringing to great masses of the population, artists tended to bypass these social issues.

Seymour's caricature is a direct reflection of the controversies that raged in Parliament and the press from the 1820s to the 1840s over the railroad bills, which were to allow rapid expansion of railroads throughout the country. Conservative interests, tied to the earlier transport systems of inland waterways and horse-drawn coaches, feared that these new mechanical monsters would destroy their privileges.

One way of dealing with the antagonistic machine was to humanize and ridicule it. Seymour depicts steam as another refinement in the life of the rich and the idle.

Steam Typesetter (caricature from a 19th-century English printing magazine)

The Bettmann Archive

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Unknown French artist
19th century
☀ *Poster for*
"L'Eolienne." c. 1834,
destroyed
Formerly collection
Charles Dollfus, Paris

By the end of the fifteenth century, sailing vessels for long-distance voyages had assumed almost the form they were to retain for another 350 years. The rapid rise of an industrial society then gave the impetus for building even swifter ships, which were rigged with as much sail as possible in order to speed up the competitive trade with China, or round Cape Horn to California after gold was discovered there. The giant clippers of about 1850, with their complicated rigging adapted to winds of many forces, represent the highest development of the sailing vessel. Ironically, they were being built just as steam was beginning to assume a dominant role.

Though the great sailing ships, with their extremely flexible and adaptable tackle, are great technological achievements, they somehow seem based on a non-mechanistic conception. They derive their power by operating in direct collaboration with the wind, whereas steamboats, by applying another source of energy, seem intent on defying and subjugating natural forces.

From about 1600 on, there were many attempts to use sails for locomotion on land. A very ambitious effort was that made by M. Hacquet of Paris, who construc- ed the "Eolienne" in 1834. The wagon is reported to have had two successful tryouts in September of that year.

George Cruikshank
British, 1792—1878

◎ *All the World Going To See the Great Exhibition of 1851* (illustration for *The Adventures of Mr. and Mrs. Sandboys and Family . . .* Part I)
London, 1851
Etching, $11^{6}/_{8} \times 16^{7}/_{8}''$ (sheet)
Prints Division,
The New York Public Library,
Astor, Lenox and Tilden Foundations

Almost all the world did. "The Great Exhibition of the Works of Industry of All Nations" was the first industrial fair of international scope, and over 6,000,000 visitors came. They saw more than 100,000 items, presented by 13,937 exhibitors and ranging from the Koh-i-Noor diamond to a "comic electric telegraph and key-board" that used facial movements to indicate letters and words. The total effect could be overwhelming. "I find I am 'used up' by the Exhibition. I don't say there is nothing in it; there's too much," sighed one visitor — Charles Dickens.[10]

This was the first time that industry, machines, and industrial materials ranked side by side with the arts. Besides divisions devoted to the fine arts and "miscellaneous," there were divisions for raw materials, machinery, textiles, and metallic, vitreous, and ceramic manufactures. The exhibition was a true manifestation of the nineteenth century's faith in progress. The Prince Consort, Chairman of the Royal Commission, declared: ". . . man is approaching a more complete fulfilment of that great and sacred mission which he has to perform in this world. His reason being created after the image of God, he has to use it to discover the laws by which the Almighty governs his creation, and . . . conquer Nature to his use . . . The Exhibition of 1851 is to give us a true test of the point of development at which the whole of mankind has arrived in this great task . . ."[11]

The exhibition was to be the model for a long series of world's fairs, perhaps the most typical expressions of the century's materialistic evolution. All the newest technical achievements were to be shown at these fairs, but their art sections were, without exception, horrifying displays — an evidence of the meretricious standards of official taste prevailing at the time.

The construction of the great iron and glass Crystal Palace that housed the exhibition was a truly astonishing feat. Joseph Paxton made his first sketch for it in June, 1850; construction began in September; and it was completed the following January. The length of its main building was 1,851 feet, to correspond with the year of its erection. The whole building was dissected by Paxton into a simple system of small, prefabricated units put together on the site. Siegfried Giedion has written of it:

The possibilities dormant in modern industrial civilization have never since, to my knowledge, been so clearly expressed . . . . In the Crystal Palace an artistic conception outdistances the technical possibilities of the era — something which is very rare in the nineteenth century. . . . The curious association of an unmistakable grandeur with a certain gentleness was never again to be achieved. From now on, development will come for decades at the hands of the engineer. He will achieve the new solutions.[12]

Winslow Homer. American, 1836—1910
◎ *Rocket Ship.* 1849
Pencil, $3^3/_4 \times 15^1/_8$″
Museum of Fine Arts, Boston (gift of Edwin A. Wyeth)

Winslow Homer drew this rocket ship at the age of thirteen. It advances through the skies at an incredible speed. Homer's imagination, which foreshadows Jules Verne's science fiction, is accurate as well as fantastic: though the machine has an animal's snout, it is clearly jet-propelled. In the left corner of the drawing, the space rider crashes. The exactitude and wealth of detail are typical of a child's conception of life and his sense of realism.

From another starting point, Mr. Golightly is borne through the air by his "new patent, high pressure, Steam Riding Rocket." The names of the patent holders are Quick and Speed. The craft seems far more plausible than the one labeled "Flying by Steam" in Seymour's almost contemporanous *Locomotion* (page 27). This steam-powered machine is functional in its construction, and even Mr. Golightly himself is streamlined.

If Homer's drawing marks a high point of childish imagination, Mr. Golightly purports to represent "The Flight of Intellect," or at least of constructive engineering thought. The results are strikingly similar.

Unknown British artist. Mid-19th century
◎ *The Flight of Intellect* ("Portrait of Mr. Golightly experimenting on Mess. Quick & Speed's new patent, high pressure Steam Riding Rocket")
Lithograph, G. E. Madeley, London. n.d. $8^1/_2 \times 11$″
Princeton University Library, Princeton, New Jersey
(Harold Fowler McCormick Collection of Aeronautica)

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Pyramaxos of Goozeria.
THIS ENGRAVING OF THE FIRST CARRIAGE, the "ARIEL"
is respectfully presented to the Patrons of
THE AERIAL TRANSIT COMPANY,
by their humble Servants,
The Publishers.

W. L. Walton. British, active 1834—1855

☀ *Aerial Steam Carriage* ("First Carriage, the 'Ariel,' The Aerial Transit Company"). Published by Ackermann and Co., March 28, 1843
Colored lithograph, $8^3/_4 \times 5^5/_8''$
The Metropolitan Museum of Art, New York
(gift of Paul Bird, Jr., 1962)

In 1843, posters were distributed all over London, depicting an enormous air locomotive flying over the Egyptian pyramids and the distant shores of India and China. They advertised the newly organized "Aerial Transit Company" for regularly scheduled departures to all parts of the world. The year before, William Samuel Henson had applied for a patent for a "Locomotive Apparatus . . . for Conveying Letters, Goods, and Passengers from Place to place through the Air."

To Henson, born and raised in England when the first railway was under construction and the first steam vessels crossing the Atlantic, steam was the natural solution to propulsion. His ideas on aviation were based on studies by Sir George Cayley (1773—1853), who had written on aerial navigation and built gliders.

With its slightly arched wings, screw propellers, and birdlike tail section, the "Ariel" looks surprisingly modern; and indeed, Henson was a true pioneer in the field of heavier-than-air craft, having been the first to envisage the modern propeller-type monoplane. But "Ariel" could never leave the ground, for its engine was far too heavy. After many near successes and final failures, Henson gave up in disgust. This curious large-scale advertising campaign anticipated by almost a quarter of a century the formation of the Aeronautical Society of Great Britain in 1866 and was the premature expression of a dream that was not to come true for almost a century.

James Boydell. British, 1803—1859

🚗 *Traction engine.* Photograph by Spencer. 1857
Photograph, 6½×8½″
Science Museum, London

This photograph of Boydell's steam-driven tractor engine is the earliest photograph of an "automobile" — a self-powered car. Boydell had invented a system of transverse paddles to be applied to wheels covering difficult terrain; he perfected and adapted it to be used by tractors in ploughing or hauling military wagons.

Perhaps never since the Renaissance have men felt more unconditionally certain of their capacities than did the engineers of the nineteenth century. Their faith in progress and steady development was limitless.

There is something fabulous in this aspect of modern history; the men are acclaimed heroes and the machines, as they quickly become obsolete, are consecrated not only in museums but in the affections of the public. There is a characteristic expression on the faces of the men in these photographs, one of pride, determination, faith. However optimistic the invention may be, the inventor-operator shows no sign of doubt when faced by the camera: even in failure he cannot be made to feel ridiculous.[13]

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THE FLIGHT OF INTELLECT.

Portrait of Mr. GOLIGHTLY,
experimenting on Mess. Quick & Speed's new patent, high pressure,
STEAM RIDING ROCKET.

Etienne-Jules Marey. French, 1830—1904

⬜ *Camera gun.* Original, 1882;
reconstruction by Coutant, Paris, 1967
(*not illustrated*), 33½″ long
Musée du Cinéma, Brussels

Camera gun and
interior of mechanism
(from E.-J. Marey, *La
Méthode graphique*, 1885)

Camera gun in use
(from E.-J. Marey,
Le mouvement, 1894)

Photographic trajectory
of tip of crow's wing
(from E.-J. Marey,
Le vol des oiseaux,
1890)

Marey, a physiologist, was the first scientist to devote himself to the study of movement, which he investigated in all its forms: in the bloodstream, the muscles, the gaits of horses, the flight of insects and birds. His fascination with the subject to which he devoted a lifetime of research led him to invent a series of apparatus for observing and recording movements that for one reason or another the eye cannot perceive. Siegfried Giedion said of Marey: "This scientist sees his objects with the sensibility of a Mallarmé."[14]

The evolution of flying machines was directly dependent on Marey's discoveries. In 1872, while studying the flight of birds, he built a working model of a monoplane with two propellers driven by a compressed air motor.

Marey constructed his photographic gun in 1882 so that he could register the successive stages of a bird's flight. The barrel houses a camera lens. The plates are carried on a revolving cylinder and changed by the action of a trigger, which permits twelve exposures a second.

Marey's methods differ considerably from those of Muybridge (pages 38—39). Marey wanted to synthesize on a single plate successive movements as seen from a single point of view by a lens that followed the trajectory of the subject. Muybridge set up his cameras side by side, so that each one in the row caught an isolated sense of movement. These two approaches are somewhat similar to those of the Cubists and Futurists in their rendering of movement and space.

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Simon Ritter von Stampfer. Austrian, 19th century
Stroboscope disc, No. 3. Published in London, c. 1832
Cardboard, 11″ diameter. Science Museum, London

During the nineteenth century, a variety of optical toys were invented. Based on the phenomenon of the persistence of vision, they can all be considered forerunners of the true moving-picture film.

One of these devices was a type of instrument invented independently in 1832 in France by Joseph Plateau, who called his apparatus the "phenakistoscope," and in Vienna by Stampfer, a professor of geometry, who named his the "stroboscope." It consists of a disc carrying on its surface a series of images, such as these hammers and wheels, in slightly different positions. When the disc is rotated rapidly, a spectator looking at it in a mirror through slots in the disc's periphery will see what appears to be continuous movement — in this case, the hammer falling on the anvil and rising again. The design of this machinery is rather unusual. Most of the preserved stroboscope discs show men riding, soldiers, couples kissing or dancing — in short, the subjects most often seen on motion-picture or television screens today.

Eadweard Muybridge. British, 1830—1904

▶ *Kicking a Hat.* 1885 (published as Plate No. 367
in *Animal Locomotion*, 1887)
Collotype, $7^1/_2 \times 16^1/_4''$
The Museum of Modern Art, New York

▷ *Zoopraxiscope.* Original 1880; reconstruction by
Robert A. Fox, 1962; with original glass disc
(gift of the Kingston on Thames Public Library)
15″ high (without base)
George Eastman House, Rochester

Eadweard Muybridge's straightforward photographic studies of motion were originally motivated by an interest quite different from Marey's scientific researches. His reputation and experience as a photographer for the United States government led the ex-Governor of California, Leland Stanford, to commission him in 1872 to take photographs of a race horse of which he was especially proud. The famous story that Stanford wished to win a bet about whether a galloping horse ever has all his feet off the ground simultaneously seems unfortunately to be apocryphal; however, Muybridge's photographs did in fact establish that, at one stage of the gallop, all the horse's feet do leave the ground and are bunched below his belly. In 1878 Muybridge attained the desired results by ranging a battery of cameras alongside a race track. Their high-speed shutters were released by strings stretched across the track, which were broken as the horses rushed past.

Later, Muybridge expanded his researches to study the movement of other kinds of animals, and of men, women, and children. He also devised an apparatus that enabled him to show the consecutive frames of his photographs in motion. His "zoopraxiscope," introduced in 1880, resembled Stampfer's stroboscope in that drawings based on photographs were mounted around the periphery of a disc made of glass. A second slotted disc was mounted in front of it, and when the two discs were rotated in opposite directions in front of a magic lantern, images flashed on the screen in rapid succession appeared to be in continuous motion. This invention made Muybridge famous, and he toured Europe and England demonstrating it to learned societies.

In Paris in 1877, Emile Reynaud began experimenting with hand-painted strips of film, which he eventually succeeded in projecting onto a screen. For a time he enjoyed great public success with his "Théâtre Optique" entertainments, but around 1911 the development of the motion picture resulted in so little interest in his marvelous cartoon films that he destroyed his projector and threw his films into the Seine in despair.

The photographic studies of movement begun by Muybridge have been important to artists from his day to our own. His contemporary, Thomas Eakins, had some

Lumière Brothers

French; Auguste 1862—1954, Louis 1864—1948

📽 *Cinématographe.* 1895
Combination camera, projector, and printer, 8″ high
George Eastman House, Rochester

The first public presentations of Lumière's Cinématographe took place in the foyer of the Paris Opera in January, 1896; but an invited audience attended a preview on December 28, 1895. Among the guests was Georges Méliès, director of the Théâtre Robert-Houdin, who some twenty years later wrote this account of the event:

The other invited guests and I found ourselves before a little screen ... and after a few moments a photograph of the Place Bellecoeur at Lyons was projected. Somewhat surprised, I just had time to say to my neighbor: "They've put us to all this bother for nothing but a magic-lantern show. I've been doing those for years." Scarcely were the words out of my mouth, when a horse dragging a truck began to walk toward us, followed by other wagons, then by pedestrians — in a word, the whole life of the street. At this spectacle we remained open-mouthed, stupefied, and surprised beyond words.
Then came in succession The Wall, *crumbling in a cloud of dust,* The Arrival of a Train, Baby Eating His Soup, *trees bending in the wind, then* Closing Time at the Lumière Factory, *finally the famous* Sprinkler Sprinkled. *At the end of the performance, delirium broke out, and everyone asked himself how it was possible to obtain such an effect.*[15]

Frames from "Arrival of a Train" ("Un Train arrive en gare"). 1896

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LA DAGUERREOTYPOMANIE

Théodore Maurisset

French, active 1834—1859

◉ *The Daguerrotype Craze*
(La Daguerréotypomanie)
1839
Color lithograph, $9^3/_4 \times 13^1/_2''$
(composition)
George Eastman House,
Rochester

This, the first caricature of photography, has been described by Beaumont Newhall, Director of George Eastman House:

Photography was news when the French lithographer Maurisset made fun of the first camera fans in this print of 1839. In the center of the caricature a gigantic frame is marked "Without Sun! Delivered Proof 13 Minutes." From the side door of the studio marked "Exit" people surge forth beneath the signs "Windows to Rent" and "Daguerreotype New Year's Gifts for 1840." Beyond the building another sign announces "Gallows to Rent to Engravers." The first photo fans pass by in procession, carrying the banner "Down with Aquatint," a form of engraving which Dr. Donné, hidden beneath a focusing cloth, is making by photography. Underneath a victim is pilloried in a "Machine for Daguerreotype Portraits," while a clock, with madly swinging pendulum, ticks off the minutes of exposure. The procession marches past a festive group dancing around a fuming mercury developer. Everywhere there are cameras. On wheelbarrows, carts, railroad cars, steamboats. Packed on heads, shoulders, backs, under the arm ("Portable Camera for Traveling"). Set on tripods, roofs, and even swung from a balloon. Marked "300 Francs Complete." Focused on an unwilling child, on a tightrope dancer, while crowds look on bearing banners "Section of Daguerreotype Haters" and "Section of Daguerreotype Lovers." Over this animated scene King Sol, a reflector for a crown, smiles benignly.[17]

Honoré Daumier. French, 1808—1879

◉ *Nadar Elevating Photography to the Heights of Art*
(Nadar élevant la Photographie à la hauteur de l'Art,
from *Souvenirs d'Artistes,* No. 367). 1862
Lithograph (second state), $10^1/_2 \times 8^3/_4''$
The Metropolitan Museum of Art, New York
(Harris Brisbane Dick Fund, 1926)

The balloonist with a camera in the upper right of Maurisset's caricature was a fantasy, but prophetic. The first man who actually ascended in a balloon to take photographs was Nadar, in 1856. Daumier's lithograph refers both to Nadar's twin interests, aeronautics and photography, and to the controversy that raged throughout the second half of the nineteenth century: Was photography suited only to recording fact and documenting events such as the Crimean War, or was it truly an art?

In 1853, Nadar opened a portrait studio, which soon became a meeting-place for the famous. He almost abandoned this career as his interest in aeronautics increased but resumed photography when he was unable to make a living from aeronautics. As a friend and supporter of the Impressionists, Nadar was familiar with the discussions about the status of photography and its relation to painting.

The arguments continued throughout the century. One of the most vehement disputants was Peter Henry Emerson, who in an address to the Camera Club of

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of them made into lantern slides for teaching; more recently, they have greatly inspired Francis Bacon. As Leland Stanford predicted in his foreword to Muybridge's first published album, *The Horse in Motion:* "The facts demonstrated cannot fail, it would seem, to modify the opinions generally entertained by many, and as they become more generally known, to have their influence on art."[16] In a different area, studies of motion were applied in the course of research in the newly developed field of "scientific management." Around 1912, the American production engineer Frank B. Gilbreth analyzed in detail the movements of manual workers. His aim was to obtain better working conditions, but the result was that management often attempted to drive the workers harder in order to speed up production. Let us hope that we are now moving toward another result — mechanization that will relieve man of all tasks that machines can perform.

Alphonse M.A. de Neuville
French, 1835—1885

◎ *Captain Nemo's Bedchamber
on the "Nautilus"*
(from Jules Verne's *Voyages
Extraordinaires:
Vingt Mille Lieues sous les Mers*)
Paris, 1870
Woodcut, 5 × 3½"
Private collection, Stockholm

Jules Verne represents an optimism based on un-limited confidence in science and the scientist, during the peak of the nineteenth century's belief in progress and industry. He did not see the despair that mechanization and industrialization were bringing to a large part of Europe's population in his day; and he dismissed the Commune as "a trifle." His many books attracted an enormous public that gladly mingled fact with fiction.

Captain Nemo's "Nautilus" ran on electricity. "There is a powerful agent," he said, "which is the soul of my mechanical devices. That agent is electricity." Nemo believed in electricity with the same conviction that Lenin was later to hold; his concern, however, was not with society, but exclusively with himself and his ship. He is the incarnation of the lone technician whose genius dominates nature and enables him to force his way through the world.

Verne's books are filled with these mastermen, the epitome of the century's engineers. His romantic science-fiction was based on a conception of science that believed the universe could be mapped out in mechanical terms, and that its structure was built upon "laws" that would last forever. His supermen heroes make use of these laws to attain mastery, just as the ruling classes in his day laid down supposedly natural laws to govern society. It never seems to have occurred to them that their laws were empirical and inevitably reflect the imperfections of the minds that formulated them. In any event, the instrument room of the "Nautilus" as depicted by Neuville does not inspire great confidence!

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NADAR élevant la Photographie à la hauteur de l'Art

London in 1886 proposed a scientific basis for art, citing the most recent theories about optics and retinal perception. He came to the conclusion that photography was "superior to etching, woodcutting and charcoal drawing" in its ability to render perspective, and second to painting only because it lacked color and the ability to reproduce exact tonal relationships.[18] The result was a storm of controversy. In 1891, Emerson reversed his position, declared that he had erred in confounding art with nature, and in a black-bordered pamphlet, *The Death of Naturalistic Photography,* decided that the me-dium had too many limitations to rank as anything but "the lowest of all the arts ... for the individuality of the artist is cramped, in short, it can scarcely show itself."[19]

But evolution had outstripped Emerson. By opening up new ways of seeing, photography had already revolutionized art. The camera's analytical perception was essential for the Impressionists and Post-Impressionists. Photography destroyed academic preconceptions; and our present ways of seeing are probably as greatly influenced by camera work as pre-Impressionist ways of seeing were influenced by Renaissance art.

Camille Lefèbvre
French, 1853—1947
⊚ *Monument to Emile Levassor.* 1907
Marble relief (after Jules Dalou, 1838—1902), Porte Maillot, Paris

This monument stands at the Porte Maillot in Paris, the finishing point of the great automobile race from Paris to Bordeaux and back, June 10—12, 1895, which it commemorates. The race was won by Emile Levassor (1884—1897), engineer and car manufacturer, driving his famous two-seater Panhard-Levassor "5." By winning easily over his nearest competitor, Levassor established the superiority of cars with gasoline-combustion engines over those powered by steam or electricity.

As this detail of Levassor's monument shows, the sculptor has faithfully rendered in marble the car's mechanical parts, the victorious driver, and the cheering spectators. This triumph of illusionism is also a monument to the lack of contact between art and technology at the time. The difficulty with which the car extricates itself from the surrounding people and vegetation is indicative of the misconceptions that still had to be overcome.

Georges Méliès. French, 1861—1938

📽 *Set for "Impossible Voyage"*
(Voyage à travers l'Impossible). 1904

George Méliès began as a magician and director of a theatre that specialized in illusionist spectacles. When he witnessed the first presentation of Lumière's motion pictures, he immediately offered a large sum to buy the apparatus but was refused. Undiscouraged, he bought and experimented with other kinds of photographic equipment and eventually became producer, author, photographer, decorator, actor, and film director. At the turn of the century, he dominated an epoch in the history of film.

Transferring his interest in trick effects to the motion picture, Méliès created a new art form, which presented a romantic-ironic image of the world of technology and machinery. The motion picture was for him, above all, a machine of enchantment. Beginning with *A Trip to the Moon* in 1902, he made a long series of films — *Impossible Voyage, The Conquest of the Pole, Under the Sea,* and so forth. In these films, Jules Verne's optimistic outlook and unlimited confidence in progress and science were subjected to a light, good-natured scepticism, and often exaggerated to the point of the ridiculous. Méliès injected a healthy doubt into people's unwavering faith in science, by making vast technological and scientific enterprises appear too easy to be believed by even the most credulous. His space ships made a trip to the moon as easy for passengers as a tram ride. By a technological feat of an artistic kind, he mocked those who placed too great confidence in technology.

Pierre Selmersheim. French, 19th century

🚗 *Maquette of car for*
Le Concours de Magasins du Louvre
Original c. 1895, destroyed

When, in the final years of the last century, motor cars began to atrract great popular interest, many people were upset by their "hideous forms." The lack of sincerity that prevailed in most architecture of the time was here manifested again. One would have been as reluctant to reveal the car's construction and technical parts as society hostesses of the time would have been to show their kitchens.

At least two competitions were held in Paris in an attempt to find more beautiful forms for automobiles. The first, organized by the newspaper *Figaro*, produced a series of designs principally inspired by eighteenth-century sedan chairs or Venetian gondolas. Their engines were carefully concealed behind rococo gilt-framed panels painted with flowers. The anachronism was perceived, however, and *Figaro* admitted that: "Unhappily, we have not been able to celebrate the hoped-for marriage between Art and Science and are barely able to feel that we have brought about their engagement.[21]

The following year, another competition was sponsored by the big department store, Magasins du Louvre. The results were not much more satisfactory, and the jury decided not to award the three medals that had been announced but only to give a money prize. This went to M. Selmersheim, who had made the model illustrated above. Considering its date, and making allowance for the collapse of the front (the maquette, now lost, was probably of wax), it is not without fascination. The jury gave the following opinion:

*The jury was happy to offer a prize of 500 francs to model No. 22. One feels that this kind of projectile or moving catapult, fashioned to cleave the air, is quite ready and able to devour space. Placed high, like the watch officer on the bridge of his ship, the driver is not distracted by the conversation of the passengers. If the originator of this project had given his imagination free rein (!), however lacking in poetry his conception may be, there is no doubt that this truly talented artist would have been rewarded with a medal. He is the only one who has manifested a half-hearted desire to leave the beaten track to which we are confined and break old molds."[22]

Henri de Toulouse-Lautrec. French, 1864—1901

◎ *The Motorist.* 1896
Lithograph, 14⅝×10½" (composition)
The Art Institute of Chicago

Lautrec focuses on the driver, not the machine. His motorist is ferocious, indeed demonic — he rather than the car seems the source of the belching smoke. He is juxtaposed with the lady pedestrian as if they were Beauty and the Beast. But the satire is rather affectionate. In fact, the motorist was the artist's cousin and companion, Gabriel Tapié de Céleyran, then a medical student. Lautrec had several friends among the pioneer motorists. — David Sylvester.[20]

Lyonel Feininger. American, 1871—1956

◉ *The Old Locomotive ("Windspiel"). 1906*
Lithograph, $6^{1}/_{4} \times 12^{5}/_{8}''$
The Museum of Modern Art, New York
(gift of Mrs. Lyonel Feininger)

The earliest impressions I had of machinery were the trains, the locomotives, half terrifying and wholly fascinating . . . I used to stand on one of the footbridges over the Fourth Avenue tracks of the New York Central . . . At the age of five years I already drew, from memory, dozens of trains . . . the black locos of the N.Y.C. with "diamond" smokestacks, and the locomotives of the N.Y., N.H. and H.R.R. with elegant straight smokestacks painted, like the driving wheels, a bright vermillion red, and oh, the brass bands about the boiler and the fancy steam domes of polished brass . . .[23]

In his early 'teens, Feininger made precise drawings of old locomotives. His childhood interest lasted all his life, forming an important, if isolated, line within his art.

The old "Windspiel" dates from 1906, when Feininger was living in Berlin and active as cartoonist and illustrator. It is rendered as much like a human being as like a machine — a machine that has become an old man. Everything is used, battered, and very worn. Chaplin might have loved to ride West on this puffing ruin; but Feininger actually saw it somewhere along the Pomeranian shores of the Baltic.

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About 1911, a friend saw and admired the toy trains that Feininger had been making for his three small sons, the eldest of whom was then about five. A plan was made to have the trains mass-produced at the wooden-toy factory in Munich owned by the friend's father. In an enthusiastic letter of April 7, 1913, Feininger wrote to his wife: "I shall design contemporary and old types. I even intend to make some ancient, ancient trains of the 1830s . . . And the trains will have proper labels . . . The oldtimers will have the year of origin, and names, like 'Rocket,' 'Lady of the Lake,' 'John Bull' etc."[25] He became so preoccupied with designing the prototype models that he neglected his painting; however, he not only enjoyed working out all the details for the trains

but also looked forward to being able to support his family with the money they would bring in — something he was unable to do while pursuing "modern art." Production had actually begun in the spring of 1914, when the outbreak of war in August naturally put an end to this hopeful scheme.

The Lilliputian scale of Feininger's trains reduces none of the strength of the locomotives, which actually seems reenforced by the simplicity of forms and roughness of the material.

Lyonel Feininger
◎ *Toy Locomotives*
c. 1911—1913
Painted wood: above left
and far right, 7³/₄" long;
above right and second
from right, 7¹/₂" long;
third from right, 4¹/₂" long
Private collection, New York

Lyonel Feininger

◎ *Locomotive.* 1908
Oil on canvas, $17^5/_8 \times 32''$. Private collection, New York

◎ *Old American Locomotive.* 1910
Oil on canvas, $19^3/_4 \times 39^1/_2''$
Collection Mrs. Julia Feininger, New York

◎ *Locomotive with the Big Wheel.* 1915
Oil on canvas, $22 \times 47^1/_2''$
Collection Mrs. Julia Feininger, New York

Feininger's machines are often more human and sympathetic than the people he portrayed. He remained a caricaturist when painting his locomotives, but he revealed warm feelings toward them, and even love, which he often denied to his human subjects. The trains probably reflect a nostalgia for his American childhood, at a time when Feininger was living in Germany before and during the early years of the First World War.

These locomotives are at rest, being serviced and taking on water. There seems to be a harmonious rapport between them and the men who are serving them. Feininger evidently had faith in the engines; big trains and ships represented for him evolution and progress. Yet the unrestrained optimism of the nineteenth century is no longer in evidence, and its image of progress has become somewhat tarnished. The future world, it is obvious, was to be under the domination of machines, but the old optimism would be gone. Feininger is among the first artists of our century who seems to have perceived the complexity of man's relation to the machine.

TREVITHICKS.
PORTABLE STEAM ENGINE.

Catch me who can.

Mechanical Power Subduing
Animal Speed.

In February, 1804, the very first locomotive running on rails was put into operation at the Pen-y-Daren Iron Works, in southern Wales. Powered with a high-pressure steam engine, it hauled ten tons of iron and seventy men for over nine miles. This locomotive was nameless, but Trevithick's next one was called "Catch-me-who-can." George Stephenson continued the evolution of the railway, with "Mylord" and "Locomotion." The earliest use of locomotives was for mines and iron works: it was not until 1825 that Stephenson inaugurated the first railway line for cargo and passengers. Horses still continued to provide man's fastest means of transportation.

Engine names are a commentary on railway history. If you look at the Great Western locomotive lists from 1837 onwards you can watch the machine age getting under way. At first the namers of engines could not escape the conception of a relationship between gods and machines. The classical dictionary was ransacked. But in their new guise the gods lost their omnipotence. Gooch, the G.W.R. locomotive superintendent, while allowing that Aeolus, Apollo *and* Neptune *were good runners, had little to say in favour of the rest.* Vulcan, *he reported, developed serious wear and tear,* Bacchus *showed severe strain on his valve gearing,* Venus *was "the worst engine delivered."* Perseus *burst his boiler and killed three men, while* Mars, *after only three years' service as a goods engine, had his driving-wheels removed for the purpose of "transporting the equestrian statue of the Duke of Wellington from the sculptor's studio in Harrow Road to Hyde Park." A final snook was cocked at the classics when the workshops misread "Laocoön" on a blueprint and turned out a new engine called* Lagoon.

Meanwhile two of the more legitimate gods of the new age, Robert Stephenson and Isambard Brunel, were restoring order by designing a new batch of locomotives for the Great Western. Of the first of these Brunel wrote: "it would be a beautifull ornament in the most elegant drawing room." This was the famous North Star, *bearing Stephenson's favourite engine name. "Another Star," said Brunel to Stephenson, "would make us comparatively easy, particularly the Directors, who consider the Stars double Stars. Can you by extra exertions deliver us one in March?" So came* Morning Star, Dog Star, Red Star, Shooting Star *and many more, adding a new poetry as well as a new efficiency to railway practice.*

As the century advanced the romantic period claimed its engines. Ivanhoe, Robin Hood, Rob Roy, Waverley, Red Gauntlet, *to mention but a few, sped westward at the head of broad-gauge expresses. Most famous of these was* Lord of the Isles, *the stories of whose speed records are still told in the railway world. And it cannot be without significance that* Lord of the Isles, *after drawing international attention to himself at the Great Exhibition, crashed in 1852 at Aynho, derailing himself, breaking his buffer beam and smashing the station platform. The romantic period was at an end.*[24]

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Umberto Boccioni. Italian, 1882—1916
⊚ *Untitled (Speeding Automobile).* 1901
Tempera, 29$^1/_8 \times$ 50$^3/_8$"
Collection Automobile Club d'Italia, Rome

At the turn of the century, the car became the ultimate symbol of progress and the bearer of hopeful expectations, especially for young people. Automobiles were just beginning to free themselves from slavish imitation of carriages and take on a shape of their own. In Florence, young Ettore Bugatti abandoned brushes and palette to devote himself, as he said, "to a new kind of art, the mechanical" (see page 142). In 1901, before he was quite twenty, he constructed his first car. It had four motors — one for each wheel — but its exterior was not unlike the vehicle in this picture, painted in the same year by Umberto Boccioni, then nineteen.

The words one might provide for the missing balloon-captions of this picture are: The fox, closely pursued by hounds and the elegant pair of hunters, has jumped onto the luggage rack and is clinging to a cane protruding from the bags. Unaware of what has happened, the driver and his companion think themselves in the predicament of the legendary Russian travelers chased over the snow by wolves. The whip is being wielded to ward off not the fox but the dogs. It is the speeding machine rather than the humans which is saving nature from civilization.

It is a very optimistic story!

Winsor McCay. American, 1869—1934

Little Nemo in Slumberland. 1906
Newspaper sheet, printed in color, from the *New York Herald,* Sunday, October 14, 1906, 21³/₄ × 16³/₈"
Collection Woodrow Gelman, New York

Original drawing (*not illustrated*), pen, brush and ink, pencil, 16¹/₂ × 22¹/₈". Collection Mr. and Mrs. Ray W. Moniz, Highland Falls, New York

Winsor McCay started to draw his series *Little Nemo in Slumberland* in 1905 (the year in which Feininger began *The Kin-der-Kids*). McCay soon became the undisputed master of the early comics, as much because of the elegance, simplicity, and poetic quality of his drawing as because of his enormous productivity. *Little Nemo* appeared full page in color seven days a week.

Little Nemo often uses flying machines for his travels. Mostly, they are balloons of different kinds — none of them highly technical, as is natural, since they always appear in Slumberland. McCay's interest in actual technology manifested itself in 1909, when he transported Little Nemo into animated films — the first made in the United States, and among the first in the world.

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Giacomo Balla. Italian, 1871—1958

⌾ *Speed of an Automobile Series*
1912—1913

Filippo Tommaso Marinetti's Foundation and Manifesto of Futurism, first published in Paris on the front page of *Le Figaro* for February 20, 1909, was reprinted shortly thereafter in Italy in broadsides and in the literary magazine *Poesia* which he edited. It summoned Italian intellectuals to make a violent rupture with the past, embrace the mechanized present, "break in the mysterious portals of the Impossible," and open the way to the future.

Within a month, several of the younger artists rallied to the Futurist cause; and when the Technical Manifesto of Futurist Painting appeared on April 11, 1910, it bore the signature of five Italian painters: Umberto Boccioni, Carlo Carrà, Luigi Russolo, Giacomo Balla, and Gino Severini. They became the first group of artists to make their commitment to technology a central feature of their work.

As if inspired by Marinetti's declaration that "a roaring motor-car . . . is more beautiful than the *Victory of Samothrace*," Balla between 1912 and 1914 made a series of paintings of different sizes, whose subjects and titles were variations on the theme of the speeding automobile. Previously he had applied the principles of Post-Impressionist divisionism to the analysis of light, as in *The Street Light,* 1909, and of movement, as in the famous *Dynamism of a Dog on Leash,* 1912. The little dog with multiple legs and eight or nine tails is still rendered in an impressionistic way based on the close analytical observation of nature. With the car paintings, however, Balla moved rapidly toward a more abstract language, in which observed impressions are condensed into far less representational forms. In some of these pictures, one can still divine the back and head of the driver, and behind the spirals such mechanical elements as the wheels and the repeated shapes of the fenders and windshields of that period.

Balla's increasing tendency toward abstraction probably came about through his having seen paintings of the Analytical Cubist style, but his basic aim of rendering the essence of speed was characteristically Futurist. It was, of course, no accident that Balla should have chosen the car as the motif for this series of paintings, in which he first developed his advanced formal ideas.

Speed of an Automobile. c. 1912
Gouache on red paper, $25^1/_2$ (irregular) $\times 27^1/_2$"
Collection Mr. and Mrs. Joseph Slifka, New York

Speeding Automobile. 1912
Oil on wood, $21^7/_8 \times 27^1/_8$". The Museum of Modern Art, New York

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Jacques Henri Lartigue. French, 1896

🏁 *Grand Prix of the Automobile Club of France, 1912*
Photograph, $11^5/_8 \times 15^5/_8''$
The Museum of Modern Art, New York
(gift of the photographer)

The photographs that Jacques Henri Lartigue made as a child are a remarkable example of what a machine — the camera — can produce in the hands of someone without preconceived ideas of how it should be used. As John Szarkowski has remarked: "Perhaps only a greatly talented child, left to his own devices, could have made these pictures half a century ago. Such a child needs neither tradition nor training, but he does need great motivation and great talent."[26]

Lartigue loved the world around him, and he was fascinated by the transient scene. Left to himself to discover the possibilities of the camera, by the time he was ten he had already created extremely straightfor-ward and telling images of his time. Human beings have seldom been seen with such objective curiosity.

In taking this picture, Lartigue moved his camera from left to right, following the car. The interesting distortion of the image, which greatly adds to the impression of speed, is due to the fact that his camera had a focal-plane shutter that operated from bottom to top. Images made with similar apparatus established the oldest photographic convention for what a speeding automobile should look like. As Reyner Banham has pointed out, the result had such striking impact that it survived into the late 1930s and influenced the overhanging front of many American automobiles.[27]

Speed of an Automobile. 1913
Tempera, watercolor, and Chinese ink on canvas, 27⁵/₈×39³/₈″. Stedelijk Museum, Amsterdam

Study for Materiality of Lights + Speed. 1913. Tempera on canvas, 11³/₄×17″
Mrs. Barnett Malbin, Birmingham, Michigan (The Lydia and Harry Lewis Winston Collection)

Dynamism of an Automobile. 1913
Ink and varnish on paper, $21^{1}/_{8} \times 30''$. Collection Claudio Cavazza, Rome

Dynamic Expansion+Speed. 1913
Varnish on paper, $25^{5}/_{8} \times 42^{1}/_{2}''$. Collection Signorina Luce Balla, Rome

Speed of an Automobile+Lights+Noise. 1913. Oil on canvas, 34¼×51¼". Kunsthaus, Zurich

Then the silence deepened again. Yet, as we listened to the ancient canal muttering its feeble prayers, and the creaking bones of the dying, ivy-bearded palaces, we suddenly heard beneath the window the hungry roar of automobiles.

Let's go, I said, let's go, fellers, let's get away. Mythology and Mystic Idealism are licked at last. We're in at the birth of centaurs, we shall see the first angels fly. We must rattle the doors of life, test the hinges and bolts. Let's go. There on the earth is the first dawn of history, and there's nothing to match the red sword of the sun, slashing for the first time through the shadows of a thousand years.

We came up to the three snorting beasts, to lay amorous hands on their scorching breasts. I stretched myself on my machine like a corpse on its bier, but revived at once under the steering wheel, a guillotine threatening my stomach.

The wild sweep of madness whipped us out of ourselves and chased us through streets as rugged and deep as torrent-beds. Here and there a sick light in a window taught us to mistrust the fallible mathematics of our used-up eyes.

I cried, The scent, the scent alone is enough to guide these beasts.

And we, like young lions, pursued Death with its black belt dotted with pallid crosses, running on under the vast violet sky, alive and pulsating.

But ours was no ideal love lifting her sublime face to the clouds, nor a cruel queen to whom we offered our bodies twisted like Byzantine rings. Nothing, this wish to die, but the desire to be freed at last from the load of our courage.

And we sped on, flattening watch-dogs on doorsteps, curling them up under our flying tyres like collars under the flat-iron. Domesticated Death came up with me at every corner, stretching out an ingratiating paw, or flattening on the ground with a chatter of teeth, making velvet, caressing eyes at me from every puddle. Let's break out of the stuffy husk of wisdom and throw ourselves like pride-ripened fruit into the big sharp mouth of the wind . . . . Let's just give ourselves up to

Speed of an Automobile + Lights. 1913
Oil on cardboard, 19 × 26³/₄″. Collection Mr. and Mrs. Morton G. Neumann, Chicago

The car was not only the symbol of the new, but it also permitted him to convert the Futurists' love of speed into a pictorial expression of universal motion.

To understand fully the symbolic power that the car held for the Futurists, one must reconstruct in imagination the situation at that date. The automobile represented the ultimate liberty of the individual who, at the wheel of his monster-car, could be a kind of superman terrorizing the countryside. He was an heroic figure: a modern centaur, he was one with his machine, enjoying sensations that no mortal had ever experienced before.

At the same time, when the machine failed him, it could involve extreme frustration — as well as the threat of a danger both feared and desired. Although the new god could not be portrayed at the moment of its failure, the drama is clearly hinted at in Marinetti's introduction to the first Futurist Manifesto:[28]

We had been astir all night, my friends and I, under eastern lamps of copper filigree, star-dusted like our souls, for they, too, blazed with the sealed lightning of electric hearts. We had trampled out our ancestral sloth at length on rich oriental carpets, disputing to the uttermost limits of logic and blackening quires of paper with our frenzied scribblings.

A great pride swelled in our chests, for we felt ourselves alone in that hour, alone, awake and afoot, like proud beacons or forward guardposts against the hostile armies of the stars, spying out their celestial encampments. Alone with the stokers bustling about the satanic furnaces of great ships, alone with the black phantoms that fossick in the red-hot bellies of locomotives launched on their mad journeys, alone with the gesturing drunks flapping uncertainly along the walls of the city.

But suddenly we all jumped at the mighty rumble of a double-deck tram, rocking past in a blaze of coloured lights, like a village festival that the flooded Po tears without warning from its banks and sweeps through rapids and gorges, down to the sea.

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Umberto Boccioni. Italian, 1882—1916
⊚ *States of Mind: Those Who Stay.* 1911
Tempera and oil on canvas, 27⁷/₈ × 37³/₄″
Collection Nelson A. Rockefeller, New York

Whereas Balla portrayed the visual impression that speeding automobiles made upon the spectator, Boccioni was the first to set artists the programmatic goal of depicting the new emotions born of the meeting between man and the mechanized world. Boccioni was probably the most contemplative as well as the most gifted of the Futurists. Realizing how complex would be the interference of machines in people's emotional lives, he could not content himself with the over-enthusiasm displayed by some of his colleagues for the mechanical world.

In a lecture delivered at the Circolo Internazionale Artistico in Rome in May, 1911, Boccioni developed the idea of "the painting of states of mind." Before going to Paris with Carlo Carrà in the autumn of 1911 to see the most recent trends in art and prepare for the Futurist exhibition that was to take place the following winter, he had already exemplified his aims in a first version of *States of Mind*. He described these paintings to Guillaume Apollinaire: "one expressing departure, the other arrival .... To mark the difference in feeling I have not used in my painting of arrival a single line from the painting of departure."[29]

Boccioni's early sketches and first canvases of *States of Mind* were still somewhat under the influence of Edvard Munch. Highly charged with symbolism, they were filled with expressive lines that tellingly convey a sense of nostalgia and anxiety. After his encounter with the Cubists in Paris, he reorganized the composition of the three paintings, *Those Who Stay, The Fare-*

Umberto Boccioni
🌀 *States of Mind: The Farewells.* 1911
Oil on canvas, $27^3/_4 \times 37^7/_8$"
Collection Nelson A. Rockefeller, New York

wells, and *Those Who Go,* to give them a more precise spatial clarity. Included in the first Futurist exhibition in Paris (held at Bernheim-Jeune, February 5—12, 1912), the triptych was described in the catalogue preface, "The Exhibitors to the Public":

In the pictorial description of the various states of mind of a leave-taking, perpendicular lines, undulating and as it were worn out, clinging here and there to silhouettes of empty bodies, may well express languidness and discouragement.

Confused and trepidating lines, either straight or curved, mingled with the outlined hurried gestures of people calling one another, will express a sensation of chaotic excitement.

On the other hand, horizontal lines, fleeting, rapid and jerky, brutally cutting into half lost profiles of faces or crumbling and rebounding fragments of landscape, will give the tumultuous feeling of persons going away.[30]

Boccioni makes us realize that goodbyes in a railway station are not the same as those said at a stage-coach. In a station, the departures are more final — not because trains go faster and farther than stage-coaches, but because those who enter into a train become part of a system, while those who stay behind are outside that system. Those who leave become a group, although a minute earlier they may have been unknown to one another. In *The Farewells*, Boccioni shows how drastically the locomotive has split people into two groups.

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Umberto Boccioni
🌀 *States of Mind: Those Who Go.* 1911
Oil on canvas, $27^7/_8 \times 37^3/_4''$
Collection Nelson A. Rockefeller, New York

His representation of the locomotive itself is the strongest and most beautiful of all such images of the period. The numbers "6943" that rise out of its side become a clear and simple mathematical symbol of the machine's own strength and individuality. Severini, however, criticized the three paintings as "literary and unclear."

Boccioni's admiration for the train was probably tempered by his emotions concerning his first journey to Paris. On the one hand, he was leaving behind in Milan his mother, to whom he was extremely attached. On the other hand, he knew that he was about to be confronted with the Cubists and their works and realized that this would drastically change his own style of painting, and perhaps also his outlook on life. But though his formal vocabulary was indeed modified, his basic aim of expressing emotions remained unchanged. In the Paris exhibition catalogue, for whose preface he was chiefly responsible, he wrote:

One may remark, also, in our pictures spots, lines, zones of colour which do not correspond to any reality, but which, in accordance with a law of our interior mathematics, musically prepare and enhance the emotion of the spectator.

We thus create a sort of emotive ambience, seeking by intuition the sympathies and the links which exist between the exterior (concrete) scene and the interior (abstract) emotion. Those lines, those spots, those zones of colour, apparently illogical and meaningless, are the mysterious keys to our pictures.[31]

Gino Severini
Italian, 1883—1966
◉ *War.* 1914
Oil on canvas,
$36^{1}/_{4} \times 28^{3}/_{4}$"
Collection
Mr. and Mrs. Joseph Slifka,
New York

"We wish to glorify war — the only health giver of the world," Marinetti proclaimed in his Manifesto of 1909. In line with their enthusiasm as political activists, immediately on the outbreak of the First World War in August, 1914, the Futurists began intensive propaganda and demonstrations calling for Italian participation.

War was one of several related paintings of 1914—1915 that Gino Severini included in his one-man show, "First Futurist Exhibition of Plastic Art of the War," held at the Galerie Boutet de Monvel in Paris, January 15—February 1, 1916. In a concurrent article, Severini described his pictorial intentions:

I believe ... that a modern work of plastic art should not only express the idea of an object and its extension (continuité) but also a kind of plastic ideograph or

synthesis of general ideas .... For example I have tried to express the idea: War, by a plastic composition made up of these realities, Cannon, factory, flag, mobilization order, airplane, anchor.

According to our concept of ideational realism, no more or less naturalistic description of a battle field or carnage could give us the synthesis of the idea: War, better than these objects which are its living symbol.[32]

The symbols alluding to the army, the navy, and the air force, and the inscription EFFORT MAXIMUM in large capitals, parade the outward signs of heroism still to come. In some other paintings of 1915 included in his exhibition, such as *The Armored Train*, Severini portrayed a more concrete and aggressive glorification of war and the beauties he found in military equipment.

Giorgio de Chirico. Italian, born 1888

◎ *The Anxious Journey.* 1913
Oil on canvas, 29¼ × 42″. The Museum of Modern Art,
New York (acquired through The Lillie P. Bliss Bequest)

In his veneration for the past, Giorgio de Chirico was
the antithesis of his contemporaries and compatriots, the
Futurists. A recurring motif in his paintings of the years
1913—1914 is the seeming lack of connection between
the large open spaces of city squares with their sur-
rounding buildings, and the mechanical world of the
railroad. In many of these works, a locomotive hides
threateningly behind a wall in the background, with
steam rising from its smokestack. The smoking machine
seems a threat to the peaceful calm of the silent city.

De Chirico spent his childhood in Greece, where his
father was an engineer constructing railroad lines. One
of his autobiographical essays is entitled "The Son of
the Engineer." His attitude toward trains seems to have
been ambivalent. An early drawing, showing a toy train,
bears the title *Joy;* and in a short prose piece, "The Song
of a Station," he refers to the "little station" as "a divine
toy.... Little station, little station what happiness I owe

you."[33] On the other hand, according to his autobiog-
raphy, actual train travel upset de Chirico nervously to
the point of extreme illness. During his sojourn in Paris,
he was often desperately homesick for Italy, so that
longing and dread were probably intermingled in his
thoughts of a contemplated trip.

These contrasting feelings are apparent in *The
Anxious Journey.* The menace of the locomotive, seen
head on, is unusually strong. At the same time, the
engine's fury is somewhat lacking in real power;
encaged, ferocious, it is blocked by the brick wall. In
his monograph *Giorgio de Chirico*, James Thrall Soby
has described it:

*. . . an oneiric, menacing phantom, recognized suddenly,
as when one is aware of a motionless snake in one's
path . . . . The nightmarish reality of the locomotive is
sharpened by its emergence at the edge of a veritable
labyrinth of arches, winding in and out, leading no-
where. The painting is clearly a dream image, expressing
the terror of being lost in a railroad station before an
important journey, of trying desperately to locate a
train, only to discover it finally at the far end of an
inaccessible corridor.*[34]

The confusion in Epstein's thinking about *The Rock Drill* is typical of the ambivalent attitude toward machinery held then and later by many people who, for lack of a clear commitment, have been unable to define their opinions or positions toward it. As Richard Buckle has pointed out, Epstein's concept of a masked man drilling rock "held for him the fascination of a heroic, demonic, even sexual image";[36] its phallic character is especially evident in some of the preparatory drawings. At the same time, as the passage from his *Autobiography* makes clear, Epstein also felt a kind of abhorrence and fear of the figure, which he termed "menacing," "sinister," "terrible," and devoid of all humanity.

When the plaster model was exhibited in London in March, 1915, it was mounted on an actual rock drill that formed a tripod-like base. It seems almost too symbolic that Epstein ultimately took this away, thereby depriving the sculpture of most of its original meaning. His fear of the machine turned out to be too strong. Unable to resolve this undefined emotional crisis, his art and ideas thereafter lost some of their original revolutionary energy and in general took a more traditional turn.

The Rock Drill (plaster model mounted on a drill, 1915)

Jacob Epstein. British, born U.S.A., 1880—1959
◎ *The Rock Drill.* 1913—1914; cast 1962
Bronze, 28″ high
The Museum of Modern Art, New York
(Mrs. Simon Guggenheim Fund)

It was in the experimental pre-war days of 1913 that I was fired to do the rock drill, and my ardour for machinery (short-lived) expended itself upon the purchase of an actual drill, second-hand, and upon this I made and mounted a machine-like robot, visored, menacing, and carrying within itself its progeny, protectively ensconced. Here is the armed, sinister figure of to-day and to-morrow. No humanity, only the terrible Frankenstein's monster we have made ourselves into . . .

Later I lost my interest in machinery and discarded the drill. I cast in metal only the upper part of the figure.[35]

After thus describing *The Rock Drill* in his *Autobiography* some forty years later, Epstein goes on to add that: "I had thought of attaching pneumatic power to my rock drill, and setting it in motion, thus completing every potentiality of form and movement in one single work," but he abandoned this idea, deciding that it would provide "a kind of excitement . . . far removed from the nature of the aesthetic experience and satisfaction that sculpture should give."

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Wyndham Lewis
British, born U.S.A., 1884—1957
◎ *The Crowd (Revolution).* c. 1915
Oil and pencil on canvas, 6′7″ × 5′1/2″
The Trustees of the Tate Gallery, London

Wyndham Lewis was the most articulate spokesman for the short-lived movement called Vorticism, which for a few years injected feverish life into the London art scene, though what it represented is hard to pin down. A statement by Lewis in the catalogue of the group's only exhibition, held in London in 1915, announced that its three cardinal characteristics were "ACTIVITY . . . SIGNIFICANCE . . . ESSENTIAL MOVEMENT." In his autobiography, published in 1939, he declared: " 'Vorticism' accepted the machine-world: that is the point to stress. It sought out machine-forms. The pictures of the Vorticists were a sort of *machines.*"[37] Still later, in 1956, he defined Vorticism as: ". . . what I, personally, did, and said, at a certain period."[38]

Lewis regarded himself as an anti-Futurist, for the Future, he said, appeared to him "just as sentimental as the Past,"[39] and he succesfully sabotaged one of Marinetti's lectures in London in 1914. The Vorticists, nevertheless, were certainly strongly influenced by the Italian Futurists.

The Crowd, painted in the heyday of English Vorticism, may be regarded as a work of constructivist art before Constructivism. Forces of construction and destruction are juxtaposed and in battle. The painting is built up of zones of action, defined by different kinds of mechanical and geometrical forms, new and unseen in architecture at that time. Instead of human beings, there are a few robot-like figures. But the most remarkable feature of the painting is its play of scale, which gives it great monumentality. What happens within it seems to happen on a universal level.

A Vorticist, lately, painted a picture in which a crowd of squarish shapes, at once suggesting windows, occurred. A sympathiser with the movement asked him, horror-struck, "are not those windows?" "Why not?" the Vorticist replied. "A window is for you actually A WINDOW: *for me it is a space, bounded by a square or oblong frame, by four bands or four lines, merely."*
— Wyndham Lewis, 1915.[40]

66

Joseph Stella

American, born Italy, 1877—1946

◎ *New York Interpreted, III: The Skyscrapers.* 1920—1922
Oil on canvas, 8′3¾″ × 4′6″
The Newark Museum

Joseph Stella, like Epstein, was in Paris during the climactic year 1912, where he met a number of the avant-garde artists and saw the Futurist exhibition at Bernheim-Jeune. The first works that he painted after his return to America were strongly under the influence of the Futurists, especially Severini. Within a few years, however, Stella began to paint semi-abstract canvases in a style that was distinctively his own: *Brooklyn Bridge,* and the series of five huge paintings, *New York Interpreted,* of which *Skyscrapers* is one.

To Stella, New York was the embodiment of all the elements of modern civilization, and he wanted to render it thus. These paintings were to bear no judgment on the city, raise no hymn to it, tell no tourist anecdote. "New York is my wife,"[41] he said, and he spoke of the "towering, imperative vision" that the city imposed on him.

The city appeared to him as an enormous lattice, constructed by barbaric cyclopes and constantly moved by the vibrations of light and nocturnal sound. He sought to render by his colors the metallic, "steely" quality peculiar to New York.

The Futurists had insisted on dynamic motion; Stella offers a frozen Futurism, in which motion is captured by repeated verticals. The skyscrapers rise like pipes in an organ, while beneath the city the subway tunnels repeat their rhythms on a smaller scale. Instead of motion, there is stability; instead of giving a fugitive impression, Stella stresses what is both typical and symbolic. "His city soars but it has the solidity of steel and stone."[42]

Natalia Goncharova
Russian, 1881—1962
◎ *The Clock*. 1910
Oil on canvas, 41³/₈ × 31¹/₈″
Staatliche Museen, Nationalgalerie, Berlin

In the years just before and after 1910, most of the revolutionary trends in modern art found an international meeting-ground in Russia, especially Moscow. Futurism, known almost immediately by the translation in 1909 of Marinetti's Manifesto, was a literary as well as an artistic movement. In painting, it was blended with Impressionism and Cubism to form a distinctive style, one of whose leading exponents was Natalia Goncharova.

Generally speaking, the Russian Futurists seem to have had a more profound interest in the mechanical world than their Italian counterparts, who were mostly concerned with spectacular machines that embodied the sensation of speed and emitted loud noise. The Russians made more serious attempts to interpret the machines' complexity and understand their principles. The paintings that they produced, however, were often less formally accomplished and elegant than those of the Italians.

It is interesting that the Futurist program of propagating the new machine world should have developed in two European countries, Italy and Russia, which had had relatively little contact with modern industry. Perhaps only a Russian artist would have thought of making a pictorial interpretation of a clock. In most of Europe, the mechanization of time took place so long ago that everyone takes it for granted. (Only in the monasteries of Greece, such as those on Mount Athos, is the interval between sunrise and sunset still counted out as twelve hours, irrespective of season, just as in the early Middle Ages.)

By standardizing time and routinizing the hours in which man works and plays, the clock may well be the mechanical device that has most greatly changed human life; yet oddly enough, it has rarely formed the subject for painting. In Goncharova's picture, it is clearly associated with speeded-up productivity (compare Chaplin's *Modern Times*, page 157).

Kasimir Malevich
Russian, 1878—1935
◎ *Knife Grinder*
c. 1912
Oil on canvas,
$31^3/_8 \times 31^3/_8''$
Yale University
Art Gallery,
New Haven,
Collection of
the Société Anonyme

Kasimir Malevich's *Knife Grinder* seems to have particular affinities with Léger's early Cubist painting, which was well known in Russia at the time through exhibitions and reproductions. The stairs also bring to mind those in Duchamp's *Nude Descending a Staircase* of the year before (see page 75), though of course successive steps are an obvious device to use in a pictorial description of rhythmic movement.

Malevich had previously painted a number of pictures showing figures engaged in various kinds of occupations, but this is his only preserved machine subject. Here the man has become one with his machine, as his eyes concentrate on his task and his foot works the pedal that revolves the grindstone. The painting is a monument to the happy relations that may exist between a man and a very simple, transportable, outdoor device which he owns, operates, and uses to make his living.

The year after he painted this picture, Malevich's style changed radically. He abandoned Cubism and developed a non-representational type of painting, which

he called Suprematism and which he believed could best express the pure world of feeling. Many Suprematist compositions are of squares or circles, perhaps the most famous being *White on White* of 1918, in the collection of The Museum of Modern Art.

Malevich and Tatlin were leaders of the two extremes of advanced art in Russia around the years of the First World War and the Revolution. Malevich was a mystic, who came to believe in an art freed of all material or utilitarian considerations: ". . . the efficiently mechanized world could truly serve a purpose if only it would see to it that we (every one of us) gained the greatest possible amount of 'free time' to enable us to meet the only obligation to nature which mankind has taken upon itself — namely to create art."[43] Tatlin, on the other hand, who called his program the "culture of materials," declared that he was a "materialist constructivist" (in the 1920s, he called himself a "productivist"), and most of his later works are related to problems of technology (see pages 107—109, 144—145).

Raymond Duchamp-Villon
French, 1876—1918

◎ *Large Horse (Le Cheval majeur).* 1914;
cast no. 1 of second enlarged version, 1966
Bronze, 59″ high
Collection Mrs. Alan Wurtzburger,
Stevenson, Maryland

Raymond Duchamp-Villon's *Large Horse* is the first sculpture to give form to the idea of the machine as a creation independent of nature. A series of preparatory studies shows that Duchamp-Villon began with a rather traditional, realistic conception of a horse and rider. Gradually the sculpture grew more and more abstract; the rider disappeared, while the horse became increasingly less like a creation of *nature* and increasingly more like a creation of *man* — the machine.

Although certain parts of the sculpture resemble shafts and pistons, the *Horse* has rather few formal references to actual mechanical elements. The impression of movement and function results from the same kind of economy and straightforwardness that a designer of machines uses to achieve the most efficient performance of his apparatus. Welcoming the mechanical age, Duchamp-Villon declared that he had almost reached "the point where one views life in such a way that it no longer appears except in the form of a higher dynamics."[44] In contrast to Futurist works, however, in which the rendering of movement generally tends to be confused, complex, and pictorial, Duchamp-Villon's

Horse is lucid and architectural. Concentrating on an essentially static form, the artist built up tensions within it; the impression of movement derives, as in Cubism, from multiple intersecting perspectives. By an intellectual effort of great integrity, Duchamp-Villon charged the form of the *Horse* with such power that it became, in Matisse's words, a "projectile,"[45] while some of his other contemporaries called it "The Mechanical Horse, almost Steam."

In evolving his concept for this sculpture, Duchamp-Villon's ideas about the machine were surely influenced not only by the Futurists, but also by his younger brother, Marcel Duchamp, and other artists of their circle at Puteaux. In particular, it is easy to recognize the similarity between the form of the horse's head and the central parts of Duchamp's painting of 1912, *The Bride* (see page 76) — referred to by Duchamp as an "agricultural machine." A creature with no human forms, the bride nevertheless, according to Duchamp's own descriptions, functioned both as a human being and as a machine (in a metaphor similar to that implied by the term "electronic brain").

Robert Delaunay. French, 1885—1941

◎ *Eiffel Tower (La Tour Rouge).* 1911
Oil on canvas, 49¹/₂ × 36¹/₈″
The Solomon R. Guggenheim Museum, New York

The tower that Gustave Eiffel and the young Swiss engineer Maurice Koechlin constructed for the Paris International Exposition of 1889 has become a monument to the nineteenth century's practical science and technical utopianism. (Eiffel, born in 1832, was of the same generation as Jules Verne). A triumph of experience gained from bridge building, the Eiffel Tower is the brilliant solution to the problem of reaching a maximum height (just under a thousand feet) while using a minimum of material.

In spite of its rationality, the Tower was not at all appreciated by cultivated Parisians of the time, who resented it only as the rape of their fine, cultured city by technology. Just a month after the government and the city signed their contract with Eiffel, a group of three hundred right-thinking leaders of society protested in the name of good taste. The Tower might have corresponded to their ideas for bridge construction but not to their ideas for architecture. It was a time of divorce between reason and emotion; and though this "unnecessary" Tower is perhaps the most interesting sculpture of the nineteenth century, it was a long time before it was accepted as such. It was a popular success at the Exposition, but revenues from entrance fees declined thereafter, to rise again only after 1904.

The first artists to include the Tower in their pictures were probably Seurat, who painted it while it was still under construction, and *le douanier* Rousseau, who placed it in the background of his 1890 self-portrait. Pioneers in other fields also paid tribute to it; for example, the Brazilian aeronaut Santos-Dumont circled it in a spectacular dirigible flight.

Around 1910, the Tower was rediscovered by artists and poets, among them Guillaume Apollinaire, who made it the subject of one of his *Calligrammes*, and Raymond Duchamp-Villon, who wrote an article on it in 1913. Besides praising its virtuoso economy of materials (he pointed out that if the iron used in its construction were melted down into a square plate of the same area as its base, the plate would be less than 2¹/₂ inches thick), Duchamp-Villon admired its beauty and daring: "Across from Gothic Notre-Dame, the true tower of modern Paris rises on the Champ de Mars. Both works . . . are born of the same desire to build and both fulfill a similar dream of superhuman exaltation."[46]

It was above all Robert Delaunay who, beginning in 1909, made the Tower a central subject of his painting. Like other artists of the time, he found that the Tower presented a dynamic interplay of spaces, a place where forces interacted, and where the moving spectators themselves became part of the drama. It provided them with the "fourth-dimensional experience" of space-time that they were constantly discussing, and it was also a symbol of the new, dynamic, technical world which it had heralded when first it was built. To seize that feeling, a new kind of painting had to be invented. The poet Blaise Cendrars has described Delaunay's paintings of the Eiffel Tower:

He disjointed the Tower to fit into his frame, he truncated it and bent it over to give it its three hundred meters of dizzy height. He adopted ten views, fifteen perspectives. One part is seen from below, another from above, the houses surrounding the Tower are taken from the right, the left, from a bird's eye view, from the ground . . . .[47]

Lyonel Feininger. American, 1871—1956

◎ *Odin I (Leviathan).* 1917
Oil on canvas, 32 × 39½″
Collection Roman Norbert Ketterer,
Campione d'Italia (Lugano)

As as child growing up in New York, Feininger was impressed not only by powerful locomotives (see page 47) but also by the boats on the East River, close to his home. "And in the '80's I remember the Hudson, teeming with vessels, schooners, sloops, not to mention the magnificent side-wheelers plying up and down the river . . ."[48]

Years later, at Heringsdorf on the Baltic in 1912, Feininger made notes for his composition of the steamer *Odin* (or *Leviathan*, the name of the huge sea monster traditionally given to big vessels). After numerous sketches in charcoal, he completed this version of the subject. It is one of his rare pictures of steamers; in general he preferred sailboats in his semi-abstract paintings. The steamer in *Odin I,* one of the few interesting paintings of such a subject, is neither humorous nor human. Analytical and severe, it represents the resolution of Feininger's artistic ideas at the time. (*Steamer Odin II,* in the collection of The Museum of Modern Art, was painted ten years later, when he was far more concerned with the atmospheric play of light between sky and sea.)

Odin I is a much more demonic and frightening image than any of Feininger's locomotives. It looks like some powerful evil being thrusting its way ahead through opposing waves at night.

The big ocean-going liners of the early twentieth century were miniature reproductions of the society they served. There was a rigorous class system. Hidden below the elegant superstructures, the enormous machinery was operated by hard-working men, most of whom only occasionally saw the sea and the sun. Competition between the lines led to the building of ships that could push through any kind of weather to meet their schedules, and which therefore became bigger and bigger. The old notion that at sea you must collaborate with nature was entirely abandoned, for now man could force his way through almost any conditions. When the ocean sometimes took its revenge, as with the sinking of the *Titanic*, there was great astonishment.

The steamships developed a subculture of their own, with grim harbors, a rigid hierarchy of ships and men, and small colonies of the great nations that were nothing but coaling stations fringing the major waterways.

Marcel Duchamp. American, born France, 1887
◎ *Coffee Grinder*. 1911
Oil on wood, 12$^{7}/_{8}$ × 4$^{3}/_{4}$"
Collection Maria Martins, Rio de Janeiro

Late in 1911, Marcel Duchamp's brother, Raymond Duchamp-Villon, asked some of his friends among the artists to make paintings for his kitchen. Duchamp's contribution was this coffee grinder: "But instead of making a figurative coffee grinder, I used the mechanism as a description of what happens. You see the handle turning, the coffee after it is ground — all the possibilities of that machine."

In this intimate machine-painting, the mechanism is portrayed through its function and personality. Duchamp himself has recognized what a central role this work played in his development. As Harriet and Sidney Janis wrote in 1945:

Duchamp regards the Coffee-grinder as the key picture to his complete work. Looking back through the structure of his achievement, the elements, constantly in one mutation or another, in one degree of complexity or another, are all present in simple form in the Coffee-grinder: movement, already referred to; the magic of mechanics; and the inimitable flair for pointed irony.

From the time of the Coffee-grinder, physical, poetic, esthetic or ironic references to the machine are part of Duchamp's created world; the kinetics of the machine, its dynamics, energy and rhythms, machine-made products, machine forms, and the machine itself formulate its physics, fill its space. In this world, the human mechanism operates like a machine and resembles the machine; natural forces are synchronized with manmade power. Duchamp animates the machine, mechanizes the soul. Between these counter effects, motion becomes pure operation without objective or consciousness.[49]

Marcel Duchamp
◎ *Nude Descending a Staircase, No. 1.* 1911
Oil on cardboard, 37³/₄ × 23¹/₂″
Philadelphia Museum of Art
(Louise and Walter Arensberg Collection)

Marcel Duchamp
◎ *Nude Descending a Staircase, No. 3.* 1916
Watercolor, ink, crayon, and pastel over
photographic base, 58 × 35¹/₂″
Philadelphia Museum of Art
(Louise and Walter Arensberg Collection)

The first version of the painting that was to create such a sensation when shown in Barcelona and Paris in 1912, and at the Armory Show in New York the following year, dates from the same month as the *Coffee Grinder. Nude, No. 3,* a replica produced by coloring a photograph of the same size as the painting, was made a few years later for Duchamp's friend and patron Walter Arensberg, who regretted not having acquired the original at the Armory Show but subsequently added it to his collection. That Duchamp had in mind no conventional nude is evident in his statement:

. . . it is an organization of kinetic elements, an expression of time and space through the abstract presentation of motion . . . . But remember, when we consider the motion of form through space in a given time, we enter the realm of geometry and mathematics, just as we do when we build a machine for that purpose. Now if I show the ascent of an airplane, I try to show what it does. I do not make a still-life picture of it.

When the vision of the Nude flashed upon me, I knew that it would break forever the enslaving chains of Naturalism.[50]

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Marcel Duchamp

◎ *The Bride.* August, 1912
Oil on canvas, $35^{1}/_{8} \times 21^{3}/_{4}$"
Philadelphia Museum of Art
(Louise and Walter Arensberg Collection)

The Bride is depicted as a well-oiled machine running on "love gasoline." This differs from all earlier mechanistic images of beings: there are no recognizable human forms, and no true machine forms either. The Bride is an entirely *new* being, a creation of man in the same sense that a machine is. In the nineteenth century, the mechanization of man had begun to be transformed into the humanization of the machine. The love-machine, in its basic concept, already foreshadows the electronic brain.

Instead of being the representation of a mechanism in movement, like the *Coffee Grinder, The Bride* is rather the depiction of ideas and the processes of thought. It is an image of thinking and of how thinking functions; and since words are the crystallization of thought, from 1912 on Duchamp's pictures seem to be images of language as much as of anything else.

In such a situation, the rational relationships between the parts of mechanical machines had an all too obvious formal pattern. Symbols like levers, shafts, and so forth were both too simple and too obtrusive. Perhaps for this reason, Duchamp penetrated into a more basic form of science — chemistry. The powers inherent in chemistry are of course more independent of man than is mechanical energy. They involve natural elements, are less subject to external control, and also have to do — like *The Bride* — with the liquids of the body. References within the pictorial apparatus of *The Bride* seem to be drawn principally from a chemical laboratory and apparently refer particularly to processes of distillation.

The irrational variety of chemistry is its forerunner, alchemy. Ulf Linde has pointed out the important role that alchemical theories played in the development of Duchamp's mythology of the bride and her bachelors (see pages 79—80). It was at the time when he was in Munich painting *The Bride* that Duchamp began to explore this enormously complex story, which was to find its fullest expression in the *Large Glass* and the multiple notes he made for it.

Question: Would you comment on the use of modern machines and science in your work?
Duchamp: People living in a machine age are naturally influenced either consciously or unconsciously by the age they live in. I think I was conscious enough when I introduced derision into that sacrosanct era. Humor and laughter — not necessarily derogatory derision — are my pet tools. This may come from my general philosophy of never taking the world too seriously for fear of dying of boredom.[51]

Just as Cimabue's pictures were paraded through the streets, our century has seen the airplane of Blériot, laden with the efforts humanity made for the past thousand years, escorted in glory to the [Academy of] Arts and Sciences. Perhaps it will be the task of an artist as detached from aesthetic preoccupations and as intent on the energetic as Marcel Duchamp, to reconcile art and the people.[52]

The prophet who wrote this in 1913 was Guillaume Apollinaire. His prediction is the more remarkable in that, at the time, Duchamp had barely begun to collect his notes for the *Large Glass* and, in terms of actual works, he had executed nothing that might have connected him in any way at all with Blériot's airplane. We know, however, that Apollinaire wrote many of his essays in *The Cubist Painters* in consultation with the artists, and we may therefore surmise that these words reflect Duchamp's own ideas about the kind of work he intended to do in the future. Neither Apollinaire nor Duchamp were at all interested in the political and social aspects of art; what this extraordinary statement anticipates is that Duchamp would change the entire conception of art. How long this might take is suggested by the vastness of the historical perspective that Apollinaire drew.

The ultimate result of Duchamp's application of energy is that everything manmade is art. Only two categories remain: art and nature. The production of machines, as manmade, manufactured objects, then comes to play a very specific role: they are manmade-women, or as Picabia (or perhaps Duchamp?) called them, "girls born without mothers" (see pages 82—83).

BROYEUSE DE CHOCOLAT - 1914

Marcel Duchamp
◎ *Chocolate Grinder,
No. 2.* 1914
Oil, thread, and
pencil on canvas,
$25^{1}/_{2} \times 21^{1}/_{4}''$
Philadelphia Museum
of Art
(Louise and
Walter Arensberg
Collection)

As a youth in his home town, Rouen, Duchamp had seen a chocolate grinder in operation in a confectioner's window. This image seems to have impressed him greatly, and he made several representations of it. Although by 1912 he had officially decided to abandon oil painting, he took it up again in 1913 to paint the first version. *Chocolate Grinder, No. 2,* a year later, is fabricated of string glued onto the canvas with paint and varnish and sewn at the intersections. Machines are manufactured of whatever kind of materials are required. The introduction of "unworthy" materials was another blow at Renaissance conceptions of art.

The *Chocolate Grinder* is the first painting to depict a machine as an object worthy of a portrait. It is difficult to know how close the likeness is, though in this version the radial threads enhance the impression of movement. The chocolate grinder was destined to become a central figure in the lower part of the *Large Glass,* a "bachelor apparatus" corresponding to the bride in the upper half. As already noted, Duchamp was relatively less interested in mechanics than in the more basic, hidden, and mysterious forces of chemistry. May one conjecture that, just as Duchamp presented *The Bride* to Picabia shortly after it was painted, he also made him a gift, so to speak, of all the beautiful forms of the mechanical machine?

Marcel Duchamp
🌀 *The Bride Stripped Bare by the Bachelors* (first study for the *Large Glass*). 1912
Pencil and wash, $9^3/_8 \times 12^5/_8''$
Cordier and Ekstrom, Inc., New York

This drawing was done in Munich in July, 1912, during the same sojourn in which Duchamp produced *The Bride.* Below his signature and the date at the bottom left, it bears the inscription: *Première recherche pour: la mariée mise à nu par les célibataires,* and in the center: *Mécanisme de la pudeur/Pudeur mécanique.*

The unusual subject of the disrobing of a bride by two bachelors has unexpected precedents. Ulf Linde has found some specific examples indicating that the underground science, alchemy, was one of the main sources of inspiration for Duchamp when he evolved the mechanics of the *Large Glass.*[53] The scene of the undressing of the young maiden is depicted in many alchemical treatises. We reproduce an illustration for a text by the philosopher Solidonius, in which the loss of color that the alchemists' material undergoes in the course of liquefaction and transmutation is likened to a young virgin being divested of her rich apparel on the eve of her nuptials, to offer herself to her bridgeroom in all her splendid nudity.[54]

Many notations for the *Large Glass* in Duchamp's *Green Box* seem to be his subsequent elaboration of ideas that originated within the system of alchemical mysticism. The "Great Work" of the alchemists was to produce gold by effecting the "philosophical marriage" of the baser, dry, male element, sulphur, and the volatile female element, mercury. These are frequently represented by a king dressed in red and a queen robed in white. The generative operation took place within a "cosmic oven," whose lower and upper parts, again, were respectively male and female;[55] the mercury was contained in a vessel of pure glass — a metaphor often applied to the Virgin. It seems likely that the upper part of Duchamp's *Large Glass* relates to the philosopher's mercury, which is the principle both of the universal love of nature and of redemption through work; while the lower part, the bachelor's apparatus, is connected with the alchemical concept of sulphur.

Bride Stripped Bare. From a manuscript of the philosopher Solidonius (after Eugène Canseliet, *Alchimie*)

Cosmic Oven
Woodcut from
Annibale Barlet,
La Théotechnie
ergocosmique,
Paris, 1653
(after Kurt Seligmann,
Magic, Supernaturalism,
and Religion)

Other notes in the Green Box also refer to "an arbor-type of the Bride." This has its parallels in the (seemingly paradoxical) alchemical concept of mercury as a naked Virgin and "arbor philosophica."[56] Perhaps the most famous embodiment of alchemical concepts is to be found in the tarot cards, which are directly connected with the Great Work. The cards in this pack, like the documents in Duchamp's *Green Box*, can be constantly reshuffled and reinterpreted. Duchamp makes many references to the *pendu femelle*. The tarot card *Le Pendu* ("Hanged One") represents sacrifice and ordeal; the characteristics associated with it seem to epitomize Duchamp's attitude toward art and life:

The purifications undergone have prepared the strong Soul for the accomplishment of the Great Work. This demands on the part of the operator absolute disinterestedness. If he owns treasures, he should disseminate them for those who will benefit by harvesting them. Renouncing the practical course taken by most human beings, he should have the courage for generous self-forgetfulness and the disavowal of any irresistibly agitating love.[57]

Mercury as Virgin and
"Arbor Philosophica"
Woodcut, from *Pandora*,
Basel, 1588
(after C. G. Jung,
Psychology and Alchemy)

Marcel Duchamp
◎ *The Bride Stripped Bare by Her Bachelors, Even*
(the *Large Glass*). Original 1915—1923; replica by
Marcel Duchamp and Ulf Linde, 1961
Oil, lead, lead wire, foil, dust, and varnish on glass,
9′3″ × 6′7/8″
Moderna Museet, Stockholm

After his initial researches, begun in 1912, Duchamp worked on the *Large Glass* itself for nine years, from shortly after his arrival in America in 1915 until he abandoned it, unfinished, in 1923. It is probably the largest single project in modern art and may also be the most important.

It is a "painting" on glass, but most of the materials used are not conventional artists' materials. It contains many dynamic elements, but no physical movement. Asked whether he had intended it as the sketch for a mobile construction, Duchamp replied: "Not at all. It is like the hood of a car; the part that covers the motor."[58] There is, of course, one kind of actual movement, for the relations between the forms on the glass and those seen through it, or reflected in it, constantly change as the spectator moves. Another kind of movement is implicit and plays a more important role. All the elements in the painting are easy to distinguish separately, but they are obviously related to one another like cogwheels in a machine: one part is decisive for the next.

Many texts have been written to explain and comment on the work. Duchamp himself has indicated its significance for him as regards the mechanical world: "The composition obviously partakes of an attitude toward machines, an attitude not in the least admiring but ironic, which I must share with Raymond Roussel, as manifested for me in the production of his *Impressions of Africa* which I saw about 1910."[59] Actually, it was in 1911 or 1912 that Duchamp and Picabia, together with Guillaume Apollinaire, attended a production of Roussel's play, in which, as in the writings of Alfred Jarry, machines are intimately connected with sex.

The *Large Glass* can be read as an intricate machine. Its mechanics are described in detail in the documents regarding its genesis, inventory, and instructions for use that Duchamp published in 1934 (intentionally presented unbound and in random order.)[60] With the help of this collection, one can distinguish a kind of verbal movement, also; a constant change in the functions or identities of the different parts is produced by ambiguities and puns. The ambiguities become multiplied when one looks at the glass itself. Perhaps these changing significations can be regarded as among the more important fuels for the machine of the bride and the bachelors. The most intimate and sentimental feelings and relations of the human race are treated in the language of an instruction manual; and the relations between the bride and her bachelors are hardly conventional ones.

Fille neé sans mère (Girl Born without a Mother)

Francis Picabia. French, 1879—1953

⊚ *Fille neé sans mère (Girl Born without a Mother).* c. 1915
Pen and ink, $10^3/_8 \times 8^1/_2''$
The Metropolitan Museum of Art, New York
(Alfred Stieglitz Collection, 1949)

One of the most fruitful encounters in all modern art was that which took place in 1910 between Marcel Duchamp and Francis Picabia, eight years his senior. For both men, all existing modes of art seemed inadequate for the expression of modern concepts, and therefore new means had to be found.

Central to their thinking were ideas about the machine and its erotic significance. After attending together the performance of Roussel's *Impressions of Africa* (see page 80), the two artists must have had many discussions on this theme in the years during which Duchamp was developing the ideas that were to culminate in the *Large Glass;* and his gift of *The Bride* to Picabia in 1912 can hardly have been made without reference to its content.

On the vessel that brought Picabia and his wife to the United States for the first time, in 1913, to attend the Amory Show in New York, he became fascinated with a dancer, Mlle Napierkowska. His memories of her seem to have become interwoven with his ideas about the mechanical world. It was not, however, until he arrived in New York on his second visit, in 1915, and renewed his close contacts with Duchamp, that Picabia fully discovered the potentialities of the machine. In an interview that he gave in Duchamp's studio that October, he declared:

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Francis Picabia
◉ *Fille née sans mère (Girl Born without a Mother)*
c. 1917
Gouache on railway-machine diagram, $19^{5}/_{8} \times 25^{1}/_{2}''$
Collection Mr. and Mrs. Arthur A. Cohen, New York

This visit to America ... has brought about a complete revolution in my methods of work .... Prior to leaving Europe I was engrossed in presenting psychological studies through the mediumship of forms which I created. Almost immediately upon coming to America it flashed on me that the genius of the modern world is in machinery and that through machinery art ought to find a most vivid expression ... I don't know what possibilities may be in store. I mean simply to work on and on until I attain the pinnacle of mechanical symbolism.[61]

Picabia, perhaps acting on a suggestion made by Duchamp, called the machine the "girl born without a mother" — a female being, created by man. It may be significant, with reference to Duchamp's ideas about alchemy, that its practitioners regarded alchemy as a magical means of fertilization whereby a child can be generated without a mother. The phrase "daughter born without a mother" to characterize the machine had been used by Paul Haviland in an article that appeared in the autumn of 1915 in *291*, the review published by Alfred Stieglitz, with whose gallery Picabia had been closely associated ever since his first visit to America. Picabia himself subsequently gave the title *La Fille née sans mère* to the collection of poems and drawings that he published in Lausanne in 1918.

VOILÀ LA FEMME

Francis Picabia

◎ *Voilà la femme (Behold the Woman)*. 1915
Watercolor, oil, and gouache, $28^3/_4 \times 18^7/_8$"
Collection Robert Lebel, Paris

Voilà la femme is one of Picabia's first machinist paintings. It is of a relatively simple kind, in which machine forms completely dominate the pictorial language. The female apparatus ("girl born without a mother") is a kind of pump or compressor. This monumental image reveals how impressed Picabia was by machines when he first discovered them.

As a background to understanding the content of the works from Picabia's machinist period, 1915 to about 1922, one should realize how turbulent a life the artist led during those years. Born in France of a Cuban father and a French mother, he made two trips between Europe and New York during the war years, with the threat of being charged with desertion from French

military service constantly hanging over his head. His energies were divided between participation in the artistic activities of his friends in America and the diplomatic missions to Cuba that were the pretext for his transatlantic voyages. His sentimental life was extremely confused, his health became undermined by drugs and alcohol, and he suffered from neurasthenia.

For Picabia, machines represented a new, unsentimental, "mechanical" kind of life that he tried to lead, free from any conventional restrictions or responsibilities. The idea that machines have no morals was one that he found highly attractive. He used his love of the machine as a platform for a pyrotechnic display of his attitude toward life — skeptical, ironical, hedonistic.

Francis Picabia
◉ *Tableau peint pour raconter non pour prouver
(Picture Painted To Relate Not To Prove).* 1915
Pen and ink and gouache on tracing paper,
8×6″ (composition)
Collection Carl Fredrik Reuterswärd, Stockholm

This is the sketch for an important machine painting that has now disappeared (as has *Cannibalism,* another work of Picabia's in which the influence of Duchamp's *Large Glass* is strongly apparent).[62] In the finished painting, the structure of the machine is more monumental. Picabia treated his machines with a free hand, taking away details, adding color. As William S. Rubin has pointed out, these works, by comparison with the illustrations in mail-order catalogues or newspaper advertisements on which some of them were based, "are as different from their commercial models as are Lichtenstein's paintings from the cartoons that inspired them. Their layout, distribution of accents, and firm contouring reflect a hand and eye still informed by the taste and discipline of Cubism."[63]

The inscription at the top, "Little loneliness in the midst of the suns," refers to the female sex-organ. Picabia's hinting at the endless love-life of machines is sometimes obvious, at other times, as in this case, discreet and private. The title and inscription are typical of the privacy of the jokes in the texts that Picabia provided as accompaniment for his pictures. He held deep convictions about the strength of machines. Their strong plastic forms not only pleased him aesthetically but also symbolized his philosophy of Nietszchean superiority. In creating the machine, man had actually been more powerful than God, because he had succeeded in creating a being stronger than himself. Part of this superiority game was to confuse the spectator.

Most of Picabia's machine paintings have very interesting titles, and many also contain inscriptions. However confusing they may seem, he himself declared that they were highly relevant: "In my work the subjective expression is the title, the painting is the object. But this object is nevertheless somewhat subjective because it is the pantomime — the appearance of the title; it furnishes to a certain point the means of comprehending the potentiality — the very heart of man."[64] The relation between a painting and its title sometimes seems close, at other times more haphazard. In a world of exaltation, the inscriptions act like mental catapults, throwing our fantasy out in all directions.

Francis Picabia
⊚ *Prenez garde à la peinture*
(Beware of Wet Paint)
c. 1916
Oil, enamel, and metallic
paint on canvas,
$36^{1}/_{2} \times 28^{3}/_{4}''$
Moderna Museet, Stockholm

After returning to Europe from his second visit to the United States, Picabia settled for a while in Barcelona and began to publish a review, which he called *391* after Stieglitz's *291*. It was issued intermittently from Barcelona, New York, Zurich, and Paris between 1917 and 1924. In the second number, one of his friends described the aesthetic shared by Picabia's circle:

. . . [To an artist of this sort] the knowledge of an object "in itself" is regarded as secondary; the principal thing is the expression of the extremely variable plastic reactions that objects can provoke among themselves, and — as regards man — the mental states that determine the spectacle of those reactions . . . . The world *of ideas and forms appears like a sympathetic cosmos filled with correspondences, relationships, and resemblances. He perceives what may be the common link between a flower and a combustion engine, between a line and an idea, a color and a memory, a love and a chemical phenomenon, a biblical personage and a doctrine of art, a piano and a comb, the sea and a streetcar. What might be taken in him as an affectation of the comic is only the result of a pure ingenuousness, a strong and sincere desire to express everything human by the most direct means. His only objective is to trust, to project into material form the realities of his inner self. So every work of art becomes the representation of a private world, re-created in a man's image.*[65]

ICI, C'EST ICI STIEGLITZ
FOI ET AMOUR

IDEAL

Francis Picabia
◉ *Ici, c'est ici Stieglitz
(Here, This Is Stieglitz).* 1915
Pen and red and black ink, $29^{7}/_{8} \times 20''$
The Metropolitan Museum of Art, New York
(Alfred Stieglitz Collection, 1949)

Picabia sometimes used in an explicit way the inviting possibilities that machine forms offered for symbolism. The meaning of these symbols, however, could be understood only by his closest friends and was completely confusing for all others. Confusion was an intentional principle in his art; and Picabia's pictures often seem to gain more from evocation than they might from a precise knowledge of their meaning.

His portrait of Alfred Stieglitz appeared in 1915 on the cover of the July-August issue of *291*. William Camfield has recently explained the circumstances that account for Picabia's portrayal of Stieglitz as a broken camera and for the accompanying inscriptions.[66] After the Armory Show of 1913, Stieglitz felt that the work he had set out to do, the introduction of modern art in the United States, had been accomplished, and he was therefore planning to close his gallery. Some of his younger associates disagreed, feeling that much still remained to be done to help Americans discover themselves through art and photography. Marius de Zayas, a close friend of Picabia's, expressed this view strongly in an article in the same number of *291* for which Picabia's portrait served both as cover and as pictorial equivalent. It may be interpreted: Here, this broken-down camera is Stieglitz, who in spite of his faith and love has failed to attain his ideal.

Francis Picabia

◎ *Portrait de Marie Laurencin.* c. 1917
Watercolor, 22×17⁷/₈″. Collection Mrs. Barnett Malbin,
Birmingham, Michigan
(The Lydia and Harry Lewis Winston Collection)

Like *Ici, c'est ici Stieglitz*, this is another of Picabia's mocking machine-portraits. Marie Laurencin was among the group of avant-garde painters and poets from Paris who settled in Barcelona during the war, where Picabia and his wife met them on returning to Europe in 1916. According to Gabrielle Buffet-Picabia, Picabia asso-

ciated the vivacious, lively Marie Laurencin with a ventilator — a breath of fresh air in this closed and isolated circle.[67] The inscriptions relate directly to the life of his model: *à l'ombre d'un boche* refers to the fact that her husband was a German, whose nationality indeed shadowed their lives during the war; *le fidèle Coco* was her dog. Such a mingling of his own private reactions with literal facts in the biography of his subject was typical of Picabia. He intentionally used this kind of mixture in his art to denote the interplay between what is easily understandable and what is completely incomprehensible.

Francis Picabia

◎ *Parade amoureuse (Amorous Parade)*. 1917
Oil on canvas, 38 × 29"
Collection Mr. and Mrs. Morton G. Neumann, Chicago

Parade amoureuse is one of the most ambitious of Picabia's surviving machine paintings, and a highly characteristic example of his great gift for marrying title and picture. Nothing in the completely irrational, non-functional machine depicted here suggests an erotic situation, beyond that which is implicit in many machines. The title, however, adds a great deal. By triggering our imagination and at the same time increasing our confusion, it enhances the effect that the painting has upon us.

Once Picabia realized the potentiality of machine symbolism, he felt that any combination, any absurdity, was possible and worth trying. In the words of Marcel Duchamp: "Picabia, being very prolific, belongs to the type of artist who possesses the perfect tool: an indefatigable imagination."[68]

This is one of the first examples in which we see the influence of de Chirico's uptilted perspective, which appears so often in Dadaist works (see pages 110, 120).

Francis Picabia
Réveil Matin
(Alarm Clock). 1919
Ink, 12½×9"
Collection
Mrs. Barnett Malbin,
Birmingham, Michigan
(The Lydia and
Harry Lewis
Winston Collection)

In February, 1918, Picabia went to Switzerland for treatment of neurasthenia. In Lausanne, he published the collection of 51 poems and 18 drawings that he entitled *La Fille née sans mère* (see page 83). It immediately attracted the attention of the Dada group in Zurich, and a few months later Tristan Tzara began a correspondence with Picabia — who up until then had not even heard the word "Dada." Early the following year, the Picabias went to Zurich to visit the Dadaists, who, they discovered, had been working for several years in a direction very similar to that of Picabia, Duchamp, and Man Ray.

The meeting of 391 and Dada was celebrated in new issues of 391 and of The Dada Review. 391 appeared on bright pink paper. Arp, Tzara, Picabia and myself contributed to the two magazines, not only with individual work but by the execution in common of an illustration for Dada Nos. 3 and 4. Every detail of this illustration is still fresh in my mind. The medium was an old alarm clock which we bought for a few cents and took apart. The detached pieces were bathed in ink and then imprinted at random on paper. All of us watched over the execution of this automatic masterpiece.
— Gabrielle Buffet-Picabia, 1951.[69]

Francis Picabia
⊚ *Mouvement Dada
(Dada Movement).* 1919
Pen and ink,
20⅛×14¼″ (irregular;
sheet)
The Museum
of Modern Art,
New York

Francis Picabia
🌀 *Le Fidèle (The Faithful One).* c. 1917
Gouache and watercolor, 23 × 18¹/₂″
Collection Mr. and Mrs. Arthur A. Cohen, New York

"Laughing, she corrects manners," and "The Faithful" inscribed above his signature, are Picabia's tributes to his wife. Richard Hunt has written of Picabia's erotic machine-pictures: ". . . their common unit is the measure of irony; to compare man's most subtle feelings, and his most passionate, noble, yet murderous ardor to the movements of a machine is to indulge a very haughty sarcasm and a great deal of auto-irony ('Making love is not modern; yet it is still what I love best.')."[70]

NOVIA

Francis Picabia
◎ *Novia (Bride).* 1917
Oil, 45⅝×35″
Formerly collection
Tristan Tzara, Paris

There are several versions of *Novia;* one appeared on the cover of the first issue of Picabia's review *391.*[71]

Picabia's machine pictures may be divided into categories. *Novia* belongs to the freest, most impressionistic type, in which machine elements are rendered without any concern for their possible functioning. At the opposite extreme are faithful reproductions of engineering drawings, in which the mechanical objects appear almost entirely unchanged, except for the addition of color (e.g. *Fille née sans mère,* page 83), or slightly altered by retouching (e.g., *Tableau peint pour raconter . . . ,* page 85). A third kind includes ordinary objects, such as the camera in *Ici, c'est ici Stieglitz* (page 87) or the windshield in *Le Fidèle* (opposite). The free drawings with vaguely mechanistic associations with which Picabia illustrated his poems, as in his volume *La Fille née sans mère,* constitute a fourth type. Finally, there are drawings, very geometric in effect, that show strictly linear elements, sometimes with the lines or background heightened with color (e.g., *Tickets,* 1917).[72]

Francis Picabia

◉ *Les Iles Marquises (The Marquesas).* c. 1916—1917
Ink, $8^{5}/_{8} \times 10^{1}/_{2}''$. Collection Paride Accetti, Milan

How freely Picabia applied titles to his machinist works is shown by the fact that the sketch for *Prostitution universelle* is inscribed *Les Iles Marquises.*

In 1921, when public interest in Picabia's paintings was at its height, a French journalist attacked his use of engineering diagrams, advertisements, and instruction manuals as sources. Picabia wrote:

So Picabia has invented nothing, he copies. Yes, he copies the working-drawing of an engineer instead of copying apples. To copy apples is understandable to everyone; to copy a turbine is idiotic. In my opinion, what is even more idiotic is that Les Yeux chauds [*one of his paintings at the Salon d'Automne*], *which yesterday was indadmissible, should now, simply because it represents a convention, have become a painting intelligible to all.*[73]

LES ÎLES MARQUISES

PROSTITUTION
UNIVERSELLE

◉ *Prostitution universelle (Universal Prostitution).* 1916. Ink and tempera on cardboard, $31^{3}/_{4} \times 43^{3}/_{4}''$
Yale University Art Gallery, New Haven, Collection of the Société Anonyme

L'ENFANT CARBURATEUR

Francis Picabia

⊚ *L'Enfant Carburateur (Child Carburetor).* c. 1919
Gouache and oil on wood, $49^3/_4 \times 39^7/_8''$
The Solomon R. Guggenheim Museum, New York

Child Carburetor is one of the works of Picabia most closely based on an engineering diagram. Since the carburetor within an automobile's motor performs the vital function of achieving the proper mixture of gas and air to ensure the firing of the cylinders, its erotic symbolism can readily be connected with the Bride's "love-gasoline" in Duchamp's *Large Glass.*

In this painting, black is used with metallic gold and silver to suggest the beauty that Picabia saw in machine forms. During his lifetime, he owned a long series of powerful sport cars. Fast, funny, free, unexplored, and independent of old institutions, they were the perfect embodiment of Picabia's life-style; moreover, their functional shapes, which had nothing to do with nature but were wholly manmade, symbolized man's creative power.

Francis Picabia
◎ *Stage model for "Relâche."* 1924
Gouache on cut paper and cardboard with wire and thread, 15¹/₂″ high × 20″ wide × 8″ deep
Dansmuseet, Stockholm

Although Picabia had formally severed his connection with the Dadaists some time before, in 1924 he undertook to design the settings and costumes for a ballet to be produced in Paris at the end of the year by Rolf de Maré's Ballets Suédois. It bore the typically Dadaist title *Relâche,* which is the word used to denote that a theatre is closed because the season has been suspended or a performance canceled. With unanticipated irony, the opening performance at the Théâtre des Champs-Elysées, planned for the end of November, had to be postponed because of the illness of the choreographer and leading dancer, Jean Borlin; when the ballet was finally produced a week later, he came on stage in a wheelchair.

Picabia's decor for *Relâche* is the culmination of his machinist period. At the raising of the second curtain (partly transparent and bearing insulting texts), the spectators were blinded by 370 spotlights with metal reflectors directed toward them. The intensity of the lighting varied with the rhythms of Eric Satie's music.

The ballet was composed of two short parts; as Satie hated intermissions, Picabia undertook to provide instead a twenty-minute film. He wrote the scenario in twenty-four hours, and a young film maker, René Clair, shot it in three weeks. It was given the title *Entr'acte,* "an interlude from the boredom of monotonous life and conventions full of hypocritical and ridiculous respect."

Shortly after the opening of *Relâche,* which received only twelve performances, Picabia withdrew from the cultural life of Paris. He built a villa in the south of France and did not come back to Paris to live until 1936.

Now, what can be said of Relâche *itself? It is perpetual motion, life, it is the minute in which we seek to be happy; it is light, riches, luxury, love, free from the conventions of shame; without a moral for the stupid, without artistic researches for snobs:* Relâche *may equally well be alcohol and opium as sports, strength, and health; it is baccarat or mathematics.*

Relâche *is the optimism of happy people, in which you will see a very beautiful woman, a very handsome man, many very handsome men; overpowering lights, all whirling in a movement as rapid and agreeable as that we experience when riding in a 300-horsepower car on the best highway bordered with trees that seem bent by the illusion speed produces . . . .* — Picabia, 1931.[74]

Georges Ribemont-Dessaignes
French, born 1884

◉ *Young Woman.* c. 1918
Oil on canvas, 28³/₄ × 23⁵/₈″
Yale University Art Gallery, New Haven,
Collection of the Société Anonyme

In 1918, a number of writers in Paris — among them André Breton, Louis Aragon, and Paul Eluard — saw Dada periodicals from Zurich and became aware of what had been going on there during the war years. The following year, Duchamp came back from New York and stayed with Picabia. They established contact with the Paris Dada group, which was soon joined by Tristan Tzara, who came from Zurich toward the end of 1919. Other artists in the circle were Duchamp's sister Suzanne, her husband Jean Crotti, and Georges Ribemont-Dessaignes, a painter and writer known to Duchamp from his frequent visits to Puteaux before the war.

Discussions among the Paris Dadaists were on a metaphysical plane, concerned with the situation of art. Duchamp seemed to them to have removed the support and border lines for traditional concepts of art. The main problem was how to fill the resulting vacuum by continuing to express oneself through images. The *Large Glass* and related works, such as the *Chocolate Grinder,* provided major inspiration. Ribemont-Dessaignes has described Duchamp as: ". . . a comet that crosses and attracts the solar system without our knowing whether it belongs to it or not. It is in the midst of space on the same road as dada, but with other seasons, days and nights. It will never pass over the same route but its light and the trail of its light has been seen."[75]

With readymades such as the *Bicycle Wheel* (page 102), Duchamp had declared that all manmade objects were art. Machines, as manmade makers of objects, then moved upward in the hierarchy, while to paint nonfunctional machines was to create a new superart. Images of irrational, mocking machines gave artists the opportunity to introduce new forms, unpredicted and dynamic, and new materials. As symbols of process, of new, dynamic, ever changing concepts, machines epitomized the complexity of the situation that Duchamp had created. Many of these machines were a kind of mocking self-portrait; the artists saw themselves as irrational machines producing irrational products, just as rational machines produced rational products.

The paintings of Ribemont-Dessaignes were strongly influenced in subject matter and technique by Picabia's machinist works. Perhaps because he found it impossible to create new pictorial images of his own, Ribemont-Dessaignes eventually abandoned painting altogether to devote himself to other forms of Dadaist (and later, Surrealist) expression. Duchamp has paid tribute to his role: "He acted 'Dada' and he gave Dada the support of his acute sense of revolt . . . . he went beyond an anti-painting or anti-writing attitude. The deepest a-metaphysical metaphysics of Dada were in great part the contribution of Ribemont-Dessaignes."[76]

Man Ray. American, born 1890

◉ *Dancer/Danger (L'Impossibilité).* 1920
Oil, airbrushed on glass, 24×16"
Collection Mme André Breton, Paris

Man Ray was closely associated with the proto-Dada activities of Duchamp and Picabia in New York. In 1920, he joined Duchamp, Katherine S. Dreier, and others in founding America's first museum of modern art — the Société Anonyme, whose collection is now in the Yale University Art Gallery. In his autobiography, Man Ray relates that he decided to include in an exhibition of the new museum "...my latest painting — an airbrush composition of gear wheels, which had been inspired by the gyrations of a Spanish dancer I had seen in a musical play. The title was lettered into the composition: it could be read either DANCER or DANGER."[77] *The Impossibility* is either identical with this painting or is a variant of it.

Like so many other artists of this century, Man Ray began as a technician. He earned his living as draftsman for a company that specialized in engineering and machinery. To speed up his work, he made use of an airbrush and one day was inspired to use it in his own art. It allowed him "to paint a picture, hardly touching the surface — a purely cerebral act, as it were."[78]

Man Ray has described *Dancer/Danger,* one of the paintings he produced in this way, as a kind of revenge on all the uninspiring rationality that he ordinarily had to depict. Three cogwheels locked together is a mechanical atrocity; of course, they cannot turn. The big wheel is another offense to the most basic mechanical laws: its cogs are not of the same size.

Man Ray
Rayograph. 1922
Photogram, $9^7/_8 \times 7^1/_4''$
The Museum of Modern Art,
New York
(gift of James Thrall Soby)

In July, 1921, Man Ray arrived in Paris, where he immediately joined Picabia, Duchamp, and others of the Dada group. While pursuing his career as a painter, he supported himself by photography. One day, an unexposed "sheet of photo paper got into the developing tray . . . and as I waited in vain a couple of minutes for an image to appear . . . I mechanically placed a small glass funnel, the graduate and the thermometer in the tray on the wetted paper. I turned on the light; before my eyes an image began to form . . . distorted and refracted by the glass more or less in contact with the paper and standing out against a black background . . ." He gave the name "Rayographs" to the accidentally discovered process, "startlingly new and mysterious."[79]

Thus, with his usual direct approach and taste for simplification, Man Ray took away the optical and mechanical side of photography and let chemicals do the whole job. As if in mockery of the mechanical world, he often showed in his Rayographs some scattered machine parts, useless but beautiful.

In Berlin at about the same date, the Hungarian painter László Moholy-Nagy was making photograms similar to Rayographs by placing three-dimensional objects on light-sensitive paper: ". . . thus not only were contours recorded and, in the case of translucent objects, texture as well, but also cast shadows. The photogram technique has been enriched by modulating the light which is allowed to fall on the object-strewn paper."[80]

Morton Livingston Schamberg
American, 1881—1918

◎ *Untitled*. 1916. Oil on wood, 19½×15½″
Collection Mrs. Jean L. Whitehill, New York

The Philadelphia artist Morton Schamberg, like Picabia, sometimes found inspiration in catalogue illustrations. This mechanical abstraction is supposedly based on a stocking machine reproduced in a catalogue borrowed from his brother-in-law, a manufacturer of ladies' hosiery; but as his brother observed when he saw the painting: "... the goddamn thing wouldn't work."[81]

Schamberg, who knew Picabia and Duchamp when they lived in New York, was one of the first to create machine compositions, in part inspired by theirs, yet representing quite another conception. Instead of becoming subjectively involved with the symbolism of machines, Schamberg's interest was purely in their forms. He creates an isolated world, complete in itself— a microcosm of quiet beauty and asymmetrical balance, ruled by laws of logic. His work reflects his natural self-control. Many years after his death, Duchamp recalled his personal charm and declared: "I felt quite close to him in his grasp of one 'future' which is our 'today'."[82]

Morton Livingston Schamberg
◎ *God.* c. 1918
Miter box and plumbing trap, 10¹/₂″ high
Philadelphia Museum of Art

In his studio on Chestnut Street, Schamberg had a leaky washbasin, which he never succeeded in repairing. Perhaps this inspired the interest in plumbing that is reflected in several of his paintings but most notably in the assemblage he called, with highly blasphemous overstatement, *God*. With this work, Schamberg picked up Duchamp's idea of the readymade and adapted it in a personal way. The juxtaposition of a miter box and plumbing trap differs in spirit from, for example, Du-champ's assisted readymade *With Hidden Noise* (1916) — two brass plates framing a ball of twine, with an unknown object concealed inside it. Schamberg's approach remains formal rather than literary; *God* actually has the same tactile qualities as his paintings. It is more consciously and less mockingly "art" than a work to which it is obviously related — the up-ended urinal that Duchamp christened *Fountain* and submitted to the Society of Independents exhibition of 1917, under the name "R. Mutt." In this connection, one also cannot forget Duchamp's statement when protesting the refusal of the hanging committee to show his entry as sculpture: "The only works of art America has given are her plumbing and her bridges."[83]

Duchamp's studio at 33 West 67th Street, New York, 1917—1918, with the original Bicycle Wheel *at left*

Marcel Duchamp. American, born France, 1887
⊚ *Bicycle Wheel.* Original 1913, lost;
replica by Per Olof Ultvedt and Ulf Linde, 1960
(not illustrated)
Bicycle wheel on wooden stool, 53¹/₈″ high
Moderna Museet, Stockholm

In 1913, Marcel Duchamp fastened a bicycle wheel upside down on a kitchen stool as an invitation to everyone to spin it. This was the first of his "readymades" — in André Breton's definition, "manufactured objects promoted to the dignity of art through the choice of the artist."[84] It is the first modern work of art to use actual motion to express its meaning. Two years earlier, in painting the *Coffee Grinder* (page 74), Duchamp had defined a mechanism through its movement. In the *Bicycle Wheel*, the machine no longer has a function. The motion is isolated, and a quite different question is posed: What is the border line between art and reality?

To understand the readymades, one must relate them to collage, discovered by Braque and Picasso a year or so before. If the artist is no longer depicting reality, but instead using parts of this reality, such as pieces of oilcloth or newspaper, as parts of his picture, how then can you decide what a work of art should be? The readymades represented Duchamp's answer to this question; they were "a form of denying the possibility of defining art."[85] As he said years later: "I came to feel an artist might use anything — a dot, a line, the most conventional or unconventional symbol — to say what he wanted to say."[86] This proposition can be demonstrated by choosing: it is the act of choice that is decisive. Duchamp chose a series of very different objects from the machinemade category: a bottle rack, a snow shovel, a steel comb, a typewriter cover — about fifteen in all, exclusive of replicas. One seems close to the conclusion that machines become the artists. Duchamp left the *Bicycle Wheel* untitled but gave other readymades titles intended to excite the imagination.

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Marcel Duchamp

⊚ *Rotary Glass Plate (Precision Optics).* 1920
Motorized construction: painted glass and metal,
3'11½" high × 3'4" wide × 6'½" deep
Yale University Art Gallery, New Haven,
Collection of the Société Anonyme

When Duchamp constructed the *Rotary Glass Plate* in 1920, he went even farther than he had with his ready-mades in abandoning conventional ideas about what constitutes a work of art. Almost half a century later, we still experience a certain difficulty in recognizing this machine as such. Man Ray, who photographed it when it was ready for its first trial, described it as: "a strange machine consisting of narrow panels of glass on which were traced parts of a spiral, mounted on a ball-bearing axis connected to a motor. The idea was that when these panels were set in motion, revolving, they completed the spiral when looked at from the front."[87]

As is often the case with Duchamp, the meaning of this art machine is a kind of visual pun. When the blades of the three-dimensional construction are set in motion, that is, when the fourth dimension is added, a spectator placed directly in front will perceive continuous circles, dematerialized and two-dimensional. Thus, by the addition of the fourth dimension, space becomes reduced to a flat, intangible surface.

An earlier effort of Duchamp's to create an interplay of several dimensions was his *Three Standard Stoppages* of 1913—1914, described by a note in the *Green Box:* "...a straight horizontal thread one meter long falls from a height of one meter on to a horizontal plane twisting *as it pleases* and creates a new image of the unit of length." In this case, of course, the element of chance enters in (used here for the first time in a work of art, and used both as technique and subject).

Duchamp was very interested in the theories and speculations of two French mathematicians, Poincaré and Jouffret, who had written about a non-Euclidean, fourth-dimensional geometry. This postulated that our three-dimensional world could be regarded as a kind of shadow cast by a fourth-dimensional reality, just as a three-dimensional object casts a two-dimensional shadow. Underlying Duchamp's optical machines is this concept of a gliding system of dimensions and realities.

Marcel Duchamp

⊚ *Rotary Glass Plate (Precision Optics).* Original 1920; replica by Per Olof Ultvedt, Magnus Wibom, and K.G.P. Hultén, 1961
Motorized construction: painted plexiglass and metal,
4'9" high × 3'10" wide × 6'4" deep
Moderna Museet, Stockholm

Marcel Duchamp

⊚ *Rotary Demisphere (Precision Optics)*
1925
Motorized construction:
metal, painted wood, velvet, and glass,
59″ high × 28″ wide × 20″ deep
Collection Mrs. William Sisler, New York

This is Duchamp's most elaborate visual-pun machine. A series of letters that he wrote from March to October, 1924, to Jacques Doucet, who had commissioned it, shows the pleasure that he took in its construction. The power of an electric motor is used to cause a white demisphere, painted with a series of black eccentric circles, to revolve. The rotation makes the demisphere appear dematerialized and seem to recede into depth instead of protruding. The visual pun is accompanied by a verbal one engraved on the outer edge of the encircling copper ring: *Rrose Sélavy et moi esquivons les ecchymoses des esquimaux aux mots exquis.*

Duchamp took the same painstaking care in choosing and placing the machine parts for the construction and the details of its base as a traditional sculptor would take in handling the clay from which he models his sculpture. After the machine was completed, however, he wrote Doucet that he hoped it would not be lent for exhibition: "All exhibitions of painting or sculpture disgust me. And I would like to avoid associating myself with them. I should also regret if this globe were to be regarded as anything other than 'optics'."[88]

Marcel Duchamp
⊚ *Sketch for Precision Optics.* 1925
Ink, $10^5/_8 \times 8^1/_4''$. Philadelphia Museum of Art
(Louise and Walter Arensberg Collection)

Marcel Duchamp
🎞 *Frames from projected stereoscopic film
(left, green; right, red).* 1920
$3^3/_4 \times 7^1/_4''$, including holder
Collection Man Ray, Paris

As early as 1920, Duchamp had anticipated the optical effects that he would achieve with *Rotary Demisphere*. According to Man Ray: "... Duchamp came to me with projects; he had conceived an idea for making three-dimensional movies. Miss Dreier had presented him with a movie camera, and he obtained another cheap one — the idea was to join them with gears and a common axis so that a double, stereoscopic film could be made of a globe with a spiral painted on it." Most of the film was spoiled in developing, but: "... we did save some film, two matching strips which, on examination through an old stereopticon, gave the effect of relief."[89] Because of technical difficulties and lack of capital, the project for what would have been one of the first three-dimensional films was abandoned.

In 1926, the year after the completion of *Rotary Demisphere,* Man Ray and Marc Allegret helped Duchamp produce the film *Anemic Cinema* (the title is an anagram). It was made by filming nineteen rotating discs, which alternately bore designs and inscriptions by Duchamp. Still later, in 1935, he developed these ideas further in a set of six "Rotoreliefs" — cardboard discs, printed on both sides with circular compositions, which when placed on a record player "turning at an approximate speed of 33 revolutions per minute, will give an impression of depth, and the optical illusion will be more intense with one eye than with two."[90] Still disdaining art exhibitions, Duchamp presented these works at a little stand he rented at the Concours Lépine, an annual fair for inventors of gadgets held near the Porte de Versailles. In this way, the most influential artist of this century demonstrated his contempt for the art world by taking his place among the technicians; but perhaps this should be balanced by a saying attributed to him: "I don't believe in art. I believe in artists."

Naum Gabo. American, born Russia, 1890

◉ *Kinetic Sculpture: Standing Wave*
Original 1920, Tate Gallery, London;
reconstruction by Wit Wittnebert, 1968 *(not illustrated)*
Metal rod with electric vibrator, over-all height
including base 24¼"

In 1920, the same year in which Duchamp constructed his *Rotary Glass Plate* in New York, Naum Gabo in Moscow made this sculpture by attaching a thin metal rod to the vibrator from an old electric doorbell. These two independent experiments were the first works in which artists used motors as an expressive means.

Five years before, while in Norway during the war, Gabo, then only twenty-five years old, built the first of his "constructed heads" out of intersecting planes of plywood. Artists such as Archipenko, Lipchitz, and Picasso had already extended the Cubist interest in space and multiple planes, and in 1914 Boccioni in the Technical Manifesto of Futurist Sculpture had proclaimed the need to "break open the figure and enclose it in environment"; but Gabo went further. For the first time, he dematerialized sculpture by making the edges of his plywood planes define the space, which became the form. In this conception, he was influenced by the scientific, mathematical, and philosophical ideas he had absorbed while a student in Munich.

In *Standing Wave,* Gabo took a step beyond his earlier sculpture by creating a completely dematerialized volume, which consists of the space defined by wave-like movements of a thin metal rod set into vibration by a source of energy. The machine is thus put at the service of art. Gabo, however, resented the need for anything so cumbersome as a motor and decided that "only future developments in heat and radio power will permit as yet unpredictable kinetic solutions."[91]

Sculpture at rest, in motion, and (at right) old photograph with piece of paper vibrating on rod

Monument for the Third International, drawing
(reproduced in Nikolay Punin's pamphlet on the tower, 1920)

Vladimir Tatlin. Russian, 1885—1953

◎ *Monument for the Third International*
Original model for tower, destroyed, 1920;
reconstruction by Arne Holm, Ulf Linde, Eskil Nandorf,
Per Olof Ultvedt, and Henrik Östberg, 1967—1968
Wood and metal with motor, 15′5″ high
Moderna Museet, Stockholm

The antecedents of Tatlin's tower are the reliefs that
he began to make in 1913 on his return to Moscow from
a short trip to Paris, where he had been inspired by
the constructions that he had seen in Picasso's studio
— musical instruments of cardboard or tin. Very soon,
however, Tatlin's reliefs departed from Cubist themes
and spatial conceptions and became "real materials in

The finished model of the tower, 1920

artistic expression's actual form of manifestation, its physical existence."[92]

The development of this conception of the real in art of course entailed the destruction of pre-existing Western aesthetics. In a penetrating article, Ronald Hunt has pointed out that the idea of the destruction of art already had a tradition in Russia going back to more than half a century before the Revolution.[93] Tatlin's ideas, therefore, at once exerted a great influence, because they expressed something that everyone felt necessary in a time of such far-reaching revolutionary changes — the denial of formal values in favor of concentration on content. For the Russian Revolution, form and aesthetics were irrelevant; it was the entire society that had to be changed. *What* was to be done, not *how*, was the question.

Content itself, however, was thought of in terms of ongoing changes rather than final results. According to Tatlin's theory, the importance of the spiral is that it is the most dynamic form. Writing about the Monument for the Third International, he declared: "Here is the resolution of the most difficult problem of culture, that of unifying the utilitarian and the purely creative form. Just as the triangle, with its balance of parts, is the best expression of the Renaissance, so the spiral is the expression of our spirit."[94]

The proposed Monument for the Third International, commissioned in 1919 by Narkompros, the People's Commissariat for Education, became the main symbol for the revolutionary redefinition of art. What made the strongest impression was the new way of using materials. For the first time, it seemed possible that an artist-engineer would bring about the long-hoped-for integration of sculpture and architecture.

The tower was conceived as a metal structure. One of the many contradictions in Tatlin's work is that he built the model in wood, though this can probably be explained by the scarcity of materials in Russia during those years, when even wood may have been difficult to obtain. Its height was to be 1,300 feet — over 300 feet higher than the Eiffel Tower; the model was about 15 feet high.

The spiral framework enclosed four glass-walled, rotating chambers. The lowest, a cylinder, was to revolve once a year and be used for conferences and the legislative council of the Third International; above this a slanting pyramid, rotating once a month, was to contain executive activities. Surmounting this was a tall cylinder, and above that, a hemisphere; the cylinder would turn on its axis once each day and would house an information center.

Recently, in the course of reconstructing the model for the tower, Tatlin's conception became apparent. His point of departure was the idea of the rotating chambers to house different functions, and turning at different speeds. Space therefore had to be provided for gears of varying sizes between vertical axes. This gave rise to the tower's slant. To support his construction, Tatlin sur-

real space." Abandoning the use of limiting frames or backgrounds, he built "corner reliefs" — constructions suspended across the corners of walls. (At about the same time, Malevich, Tatlin's rival as leader of the new Russian art, was placing his famous painting *Square on Square* in a similar position, influenced perhaps by a traditional Russian way of placing icons). Tatlin's reliefs were very roughly made, and their materials were crudely stuck together. His effort was to move from the abstract to the real and leave aesthetics behind. The materials themselves — wood, iron, glass, and concrete — were chosen because of their symbolic associations with building. In Tatlin's completely original theory, the expressive importance of these materials lay not in their form, but in their actual substance. Whereas Marshall McLuhan was later to proclaim that "the medium is the message," Tatlin was saying that "the material is the message"; he studied materials in a way similar to McLuhan's study of media. Troels Andersen has written: "Tatlin tried to establish a relationship to the real object on a plane that was as abstract as linguistic structures, and which contained as many possibilities of combination. Unlike most of his contemporaries, he did not regard the question of determined *forms* as essential; he was investigating

rounded the rotating chambers with an inclined cone made of vertical members slanting toward each other at the top. A big diagonal girder would provide communication up and down the tower. To keep all these parts together, Tatlin encircled them with two spirals. Horizontal steps connected these spirals to the cone enclosing the inner chambers. The construction of the tower is thus a very logical one, based on the requirements of the functions it was to fulfil.

Hunt has termed Tatlin's ideas for this work "mechanolatry at its most romantic." Tatlin, like Marinetti, claimed to have a "machine-heart," and one of his explanations (though perhaps not the most clear) for including moving parts in the tower was that he wanted them to resemble his heart. His devotion to machines was in fact unlimited. One of his pupils, Yuriy Annenkov, has written:

Tatlin declared that only the mathematically calculated and unvarying proportions of forms, together with the appropriate use of materials with maximum economy — that is, the complete lack of caprices, emotional flights, and the "annoying futilities" of artists — constituted the basis and absolute criterion for beauty. In order to illustrate his theory, he carefully cut up a reproduction of Rembrandt's Syndics of the Drapers Guild, regrouped the figures portrayed, and pasted it on a piece of paper which elongated the proportions of the original painting. After filling in the gaps with strokes of his pencil, Tatlin claimed, not without reason, that all these arbitrary changes had not occasioned any loss whatsoever in Rembrandt's painting, which retained its values in spite of everything. Then Tatlin opened the case of his watch, admired the perfect mechanism of its tiny wheels and springs, drew out a hardly visible screw, and tried to push it into another place. Immediately, after a jerk, the entire mechanism of the watch lay scattered on the table. And that was the end of the watch. This was his means of demonstrating that art is relative, while mechanics are absolute.

Tatlin used to say that a modern factory at work is the culminating manifestation of our times, surpassing the opera or ballet; that a book by Albert Einstein is certainly more enthralling than any of Dostoevski's novels; and that is why art today should be the standard-bearer, the vanguard, and the incentive for the advance of human culture; to serve this role, it must be useful and constructive.[95]

Tatlin's ideas were taken up by the Productivist group. Many differences of opinion arose among its members, but basically they all agreed that art in the old Western sense was dead. Tatlin himself, besides teaching, designed clothes, constructed an oven, and started to build aircraft (see pages 144—145). The theatre, in particular, seemed to be one art form that could serve as a vehicle for the new theories and the new society. In the 1920s, the programmatic theatre and the

Reconstruction of model of tower, 1968

film became the principal outlets for the ideas of Tatlin's pupils, the Constructivists and the Productivists.

The Monument for the Third International was never built. The technical potential to erect it did not exist, and the ideas of the new rulers of Russia were not always as advanced as those of its artists, though they were obliged to consider it. Among those who wrote statements about the Monument were political figures such as Trotsky and Lunacharsky, as well as artists such as Lissitzky, Malevich, Eisenstein, and Tschichold, the writer Ehrenburg, and others. Outside the circle of artists, however, no one seems to have recognized its brilliance. Nevertheless, models of the tower were constructed twice more: in Moscow later in 1920, and in a somewhat altered version for the International Exposition of Modern Decorative and Industrial Arts held in Paris in 1925. In the West, its influence was first strongly felt in Berlin, and Tatlin's theories spread from there. The Bauhaus, founded in 1921 at Weimar, was built around a program that adapted Tatlin's ideas to teaching.

It is only quite recently that the extraordinary richness of Tatlin's conceptions has again been realized to any great extent. Most of his sculptures have disappeared, and the original model for the tower (as well as the two later ones) seems to be lost forever.

Raoul Hausmann. Austrian, born 1886

⊚ *Tatlin at Home*. 1920
Pasted photo-engravings, gouache, and pen and ink,
16¹/₈ ×11″
Moderna Museet, Stockholm

While the Spartakists and the tanks of the army were fighting in the streets, the Berlin Dadaists were enthusiastically discussing the new and unknown "machine technology" that they wanted to use in their works. The decisive victory had been won by the revolutionaries

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in Berlin and the massive war machine of the Allies, particularly of the Americans, which had greatly impressed the Germans. Now they dreamed of placing new supermachines in the hands of the people rather than of the old rulers, and not as weapons of destruction but as implements to build a new and better society. Tatlin was the idol, the living incarnation of these aspirations, and his Monument for the Third International their most famous symbol.

Photomontage, or rather the collage of photographic images from many sources, was especially elaborated by the Berlin Dadaists. The camera itself is, of course, a machine for picture-making. Photomontage incorporated illustrations, and often letters, from newspapers and magazines. Hausmann, among the first to use the new technique, has told how *Tatlin at Home* took form:

To have the idea for an image and to find the photos that can express it are two different things.... One day, I was aimlessly leafing through an American periodical. Suddenly I was struck by the face of an unknown man, and for some reason I made an automatic association between him and the Russian Tatlin, the creator of machine art.

But I preferred to portray a man who had nothing in his head but machines, automobile cylinders, brakes, and steering-wheels....

Yes, but that was not enough. This man ought also to think in terms of large machinery. I searched among my photos, found the stern of a ship with a large screw propeller, and set it upright against the wall in the background.

Wouldn't this man also wish to travel? There is the map of Pomerania, on the wall at the left.

Tatlin certainly wasn't rich, so I clipped out of a French paper a man with furrowed brow, walking along and turning his empty pants pockets inside out. How can he pay his taxes?

Fine. But now, I needed something at the right. I drew a tailor's dummy in my picture. It still wasn't enough. I cut out of an anatomy book the internal organs of the human body and placed them in the dummy's torso. At the feet, a fire extinguisher.

I looked once more.

No, there was nothing to change.

It was all right, it was done! — Hausmann, 1967.[96]

One of the fine subtleties of this collage is that its original title is in English — the language of America and its machine civilization.

The Spirit of Our Time and *Tatlin at Home* use similar mechanical elements, yet the former is an ironic lampoon, the latter a tribute to a man whom Hausmann sincerely admired. The two images typify the dual position that some of the Dadaists took toward the machine, and their paradoxical ideas about it.

Hausmann was among the leaders of the Berlin Dadaists and in 1919 founded a review, *Der Dada;* his

Raoul Hausmann
◎ *The Spirit of Our Time.* 1919
Wood, leather, and metals, 12⅝" high
Owned by the artist

writings and his art were both strongly polemical. Being a Dadaist meant for him "having a keen sense of perception and seeing things as they really are." Whereas the Germans thought of themselves as "the nation of thinkers and poets," actually in Hausmann's view "the ordinary man has no more capacities than those that chance has glued on the outside of his skull, his brain remains empty."[97] To express the "spirit of our time," with its readymade, mechanical ways of thinking and acting, he selected a wooden hairdresser's dummy. The head has a naive expression, quite lovable and touching, but lacks any capacity for human thought and feeling. Hausmann has shown it, and its features, being measured and numbered in a hard, "mechanical" way.

*"Art is dead —
long live Tatlin's new machine art"*
(John Heartfield and George Grosz
demonstrating at the
International Dada Fair,
Berlin, 1920)

For the Berlin Dadaists, to adopt Tatlin's ideas was as much a political as an artistic decision. None of them had ever met Tatlin, heard him lecture, or in all probability read anything by him; but at the moment, his Constructivism and his plan for the Monument for the Third International represented the official art of the Soviet Union. Tatlin's theories were readily acceptable to the Berlin Dadaists because they implied the radical overthrow of all traditional Western art.

The First International Dada Fair, held in Berlin in June, 1920, was the occasion for particularly anti-bourgeois, antimilitaristic manifestations. The sign reading "Art is dead, long live Tatlin's new machine art." was produced for this Fair; it is shown being carried by two leading Dadaists, George Grosz and John Heartfield, who had changed his name from Herzfelde at the outbreak of the war as a gesture against chauvinism and militarism.

El Lissitzky
(Lazar Markovich Lissitzky)
Russian, 1890—1941
Tatlin Working on the Monument for the Third International
c. 1921—1922
Pencil, gouache, photomontage,
$13 \times 9^{1}/_{2}''$
Collection
Eric Estorick,
London

Enthusiasm for Tatlin and Constructivism in Germany reached a high point in 1922, when the First Russian Exhibition was held at the Galerie van Diemen in Berlin. El Lissitzky, a painter, architect, illustrator, and photographer, who had associated himself with Tatlin in Moscow and who had come to Germany the preceding year, designed and installed one of the exhibition galleries. He used the opportunity to turn it into a demonstration of Tatlin's ideas.

At about the same period, Lissitzky produced this photomontage in homage to Tatlin and his tower. It was originally made to illustrate a book by Ilya Ehrenburg, *Six Novels with Happy Endings,* printed in 1922. Lissitzky was associated with Ehrenburg in Germany in editing a polyglot magazine *Veshch/Gegenstand/Objet,* which promulgated Tatlin's ideas to an international audience. Obviously wishing to further the impression that Tatlin in his machine art worked according to strict mathematical principles, Lissitzky posed him as an engineer surrounded by mathematical symbols.

George Grosz
American, born Germany,
1893—1959

⊚ *The Engineer Heartfield*
1920
Watercolor, pasted postcard,
and photo-engraving,
16½×12″ (sheet)
The Museum of Modern Art,
New York
(gift of A. Conger Goodyear)

The "machine-heart" that both Marinetti and Tatlin claimed to have appears again in the breast of Heartfield, in this portrait of him by his friend Grosz. These "machine-hearts" have nothing to do with the old mechanistic interpretation of man as a machine but signify the degree of identification with the utopian dream of what machines might achieve in the future. Those who have machines for hearts must be very special and strong men, whose spirits are ruled by no weak, sentimental organs but by instruments of rationality and logic.

This picture, probably a gift by Grosz to his friend, makes ironic reference to one of the several times when Heartfield underwent arrest for his activities against the government. Grosz has portrayed him in a cell, looking like one of the most-wanted men; the inscription in the upper right wishes him "lots of luck in his new home."

George Grosz
⊚ "*Daum*" marries her
pedantic automaton
"*George*" in May 1920.
*John Heartfield is very
glad of it* (Meta-Mech[anisch]
konstr[uiert] nach
Prof. R. Hausmann). 1920
Watercolor, pencil,
and photomontage,
$16^{1}/_{2} \times 11^{7}/_{8}$"
Galerie Nierendorf, Berlin

This subtle work of irony and self-mockery, though done in the month of Grosz's marriage, does not relate to that event but to the discussions about art and its role in society, a topic hotly debated by the Berlin Dadaists in 1920. In "George" we recognize, of course, none other than Hausmann's sculpture, *The Spirit of Our Time*. Grosz seems to be trying to bring about a marriage between the social-realist expression in his drawings and prints (represented by the prostitute he so frequently included in them) and the more cryptic, machine-assemblage images of Hausmann and Heartfield, another master of photomontage.

It is interesting to note here an early use of the term "meta-mechanic," whose origin and meaning remain obscure.[98] It was in all probability ironic. In 1954, the same word was reinvented to designate Jean Tinguely's ever-changing reliefs and open-wire constructions (see pages 165—167).

Kurt Schwitters. British, born Germany, 1887—1948

⊚ *Die Kultpumpe (Cult Pump)*
⊚ *Der Lustgalgen (Gallows of Desire)*
Merz sculptures. Originals c. 1920, destroyed;
postcards ("*Merzpostkarte*"), 5½ × 3½"
Collection Ernst Schwitters, Lysaker (Oslo)
⊚ *Haus Merz (Merz House)*. 1920
Architectural model, destroyed

Though closely associated with some of the German Dadaists, with whom, as he said, he shared a love for "nonsense," Kurt Schwitters stood apart from them in many ways and even outspokenly opposed some of their concepts. Whereas they either took an anti-art position or wished to apply Constructivist principles for political purposes, Schwitters was strongly pro-art and quite content to create for his own private enjoyment. His approach, highly personal and complex, was closer to that of Paul Klee, whose works his frequently resemble in their small scale.

In 1918, Schwitters began to make a special kind of collage out of discarded scraps of paper and bits of junk. He gave these compositions the name *Merz,* from the second syllable of the word *Kommerz* that he had cut from an advertisement and used in one of them. Gradually he applied the term *Merz* to all his activities, which included, besides collages and reliefs, poetry and recitations, and the construction of the *Merzbau* — a gigantic, architectonic kind of static sculpture-machine that he built in his house in Hanover in the course of more than a decade. Schwitters also wrote a description for a completely irrational and unrealizable *Merz*-stage, a theatre-machine that would be a total work of art dependent on sensuous rather than literary experience.

The three small objects illustrated here (all presumably now destroyed, like the *Merzbau*) were among the first of Schwitters' three-dimensional works. He mentioned them in an article he wrote in December, 1920, in which he quoted a critic who had described *Merz House*, his first piece of architecture, as ". . . the cathedral . . . absolute art. This cathedral cannot be used. Its interior is so filled with wheels that there is no room for people . . . it has no other meaning than an artistic one."[99]

These works are typical of Schwitters' attitude to machines. He was neither impressed by nor afraid of them, but approached them as he did most other products of contemporary civilization. In a detached, unsentimental way, he seems to pity these mechanical bits and pieces that might otherwise be rejected and thrown away. In many of his constructions, the mechanical parts are isolated, exposed, and prominent. A wheel might be broken, yet it was still the central feature of the composition. The titles play an important role; like the objects themselves, they explore the depths of the irrational in a never-ending, elusive way.

DAS SCHÖNE MÄDCHEN   HANNAH HÖCH 20

Hannah Höch. German, born 1889

◎ *Pretty Girl*. 1920
Pasted photo-engravings, 15 × 12¼″
Collection S. & G. Poppe, Hamburg

Hannah Höch was one of the original group of Berlin Dadaists and a particular friend of Raoul Hausmann, from whom she learned the new technique of photomontage. In contrast to her male comrades, she did not feel that this medium should be used "to produce only polemical works, or for applied art . . . but that it could be employed simply for its expressive possibilities and that one should create with it purely aesthetic works."[100] This brought her closer to Schwitters' approach. Höch is, with him, probably the first to use the mechanical repetition of a single element to describe the effects and characteristics of the machine.

Unlike her colleagues in Germany, she also sensed the erotic implications of machines. She had probably seen some of Picabia's work, for the head of her beautiful young girl is a light bulb, and just such an electric light had appeared on the cover of the sixth number of Picabia's *391* in July, 1917, labeled *American Girl*.[101] Höch's girl, however, has a softer charm than Picabia's symbol and appears on very friendly terms with the motorized elements around her.

Kurt Schwitters
◎ *Untitled (With Machine Part).* c. 1923—1924
Cut-and-pasted paper and photo-engravings,
12½ × 9¼" (sheet)
Marlborough-Gerson Gallery, Inc., New York

Early in the 'twenties, Schwitters became estranged from those of the Dadaists who were essentially political. After a trip to Holland in 1922—1923, he was increasingly influenced by Theo van Doesburg's neo-plasticism. His work assumed more formalized tendencies, and his interest in typography was intensified.

In some of his collages from this time on, Schwitters seems to be concentrating on the mechanical characteristics of the printed materials he used in them. Much of this material resembles the kind of proofs one might find in a printing shop. Multiple repetitions of the same element, combined with printed images of machines, give collages of this sort a metallic, oily, "modern" look. They are Schwitters' contribution to the Constructivist optimism of that time, which believed so firmly in the potential of efficiency. Yet, in their complete uselessness, they retain Schwitters' characteristic note of skepticism or irony, however discreetly expressed.

Kurt Schwitters. ◎ *Untitled (H. Bahlsens Keks-Fabrik A.G.).* 1930
Cut-and-pasted paper and photo-engravings, $9^{7}/_{8} \times 6^{1}/_{4}''$ (sheet). Private collection, Switzerland

Max Ernst. French, born Germany, 1891

◎ *"Fiat Modes, Pereat Ars"* (*"Let There Be Fashion, Down with Art"*): Plate II,
Da Da NoBis . . . c. 1919. Lithograph, 17¹⁄₈ × 11″ (sheet)
The Museum of Modern Art, New York

Before the war, Max Ernst, the son of a painter, had already decided to follow the same career. He belonged to a circle of avant-garde artists and poets in Cologne and had met others during a visit to Paris. He served four years in the army, was wounded twice, and invalided in 1917. He and Paul Eluard, who became his closest friend, later discovered that in February of that year they had fought on the same front, on opposite sides.

After the war, Ernst could not travel outside Germany, since he lacked a passport. During a trip to Munich in 1919, however, he saw Dada publications from Zurich, and also the Italian magazine *Valori Plastici,* which contained reproductions of works by Giorgio de Chirico. Fascinated by the strange atmosphere and mechanistic elements in de Chirico's interiors with mannequins, Ernst produced an album of eight lithographs, *Fiat Modes, Pereat Ars,* with metallic contours and tiptilted perspective effects. Ernst later destroyed the edition; the album in The Museum of Modern Art is the only one still in existence.

Max Ernst
◎ *Self-Constructed Small Machine.* 1919
Pencil and rubbing from assembled
printer's plates, 18×12″
Collection Mr. and Mrs. E. A. Bergman,
Chicago

Ernst soon caught up with the Dada movement as it had developed in Zurich and other European centers. He took the name "Dadamax," and together with Alfred Grünewald, who adopted the pseudonym of Baargeld ("ready money"), and others, founded a Dada movement in the Rhineland. Their art, exhibitions, and publications were planned as a veritable conspiracy to overthrow the stodgy German mentality. Developing the techniques he found in Dada magazines, Ernst used them in a highly personal way. This drawing is inscribed:

Selbstkonstruiertes maschinchen in diesem verrührt er meersalat leitartikel leidtragende und eisensamen in zylindern aus bestem mutterkorn sodass vorne die ent- *wickelung und rückwärts die anatomie zu sehen ist der preis stellt sich dann um 4 mark höher. / Petite machine construite par lui-même il y mélange la salade de mer la sperme de fer le périsperme amer d'une côté nous voyons l'évolution de l'autre l'anatomie ça coute 2 sous plus cher.*

["*Self-constructed small machine in which he mixes sea salad, editorial, mourner, and iron sperm into cylinders of the best ergot so that the development can be seen in front and the anatomy in back. The price is then about 4 marks higher./A little machine constructed by himself, in which he mixes sea salad, iron sperm, bitter perisperm. On one side we see the evolution, on the other, the anatomy. It costs 2 cents more.*"]

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Max Ernst
◎ *The Roaring of Ferocious Soldiers*. 1919
Rough proof from assembled printer's plates, altered with pen and ink, $13^3/_4 \times 10^5/_8''$
Galleria Schwarz, Milan

Ernst has said that the use in his drawings and collages of figurative elements dissociated from their normal context "provoked in me a sudden intensification of my powers of sight — a hallucinatory succession of contradictory images . . ."[102] The rough printer's proofs that Ernst added to and altered by drawing on them in ink were very irrational in themselves, since the printer had placed the images with no conscious plan. Ernst's lines impose a second layer of irrationality that somehow makes the whole seem more rational. The well-organized world of German business and industry, however, found such drawings outrageously shocking.

Max Ernst
🌀 *Farewell My Beautiful Land
of Marie Laurencin.* 1919
Rough proof from assembled
printer's plates,
altered with pen and ink,
15³/₄ × 11″ (sheet)
The Museum of Modern Art,
New York

According to Ernst's recollection, the title and inscriptions of this work probably refer to Marie Laurencin's efforts to help him obtain a French visa. Together with a similar drawing called *Trophy Hypertrophied* (formerly belonging to Tristan Tzara and given by him to The Museum of Modern Art), it was made while Ernst was waiting one day in a printer's shop for proofs of a Dada publication. The Cubist-oriented Section d'Or group rejected the latter drawing for their show in Paris in 1920, on the grounds that it incorporated fragments of printed material and therefore could not be considered handmade.

Max Ernst
◉ *Untitled (Airplane).* 1920
Pasted photo-engravings, $2^3/_8 \times 5^5/_8''$
Collection D. and J. de Menil

By incorporating photo-engravings into his collages, Ernst seems to have arrived independently at a technique somewhat similar to the photomontages developed by Hausmann and other Berlin Dadaists. In 1921, at the invitation of André Breton, he showed a number of these collages at the Galerie Sans Pareil in Paris.

The full title of *The Swan Is Very Peaceful* is:

C'est déjà la vingt-deuxième fois que Lohengrin a abandonné sa fiancée (pour la première fois) / c'est là que la terre a tendu son écorce sur quatre violons / nous ne nous reverrons jamais / nous ne combattrons jamais contre les anges / le cygne est bien paisible / il fait force de rames pour arriver chez Léda.

[*"It is already the twenty-second time that (for the first time) Lohengrin has left his fiancée. / it is there that the earth has spread its crust on four violins / we will never see each other again / we will never fight against the angels / the swan is very peaceful / he paddles hard to catch Leda."*]

Max Ernst
◉ *The Swan Is Very Peaceful*
1920
Pasted photo-engravings,
$3^1/_4 \times 4^3/_4''$
Private collection, New York

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la petite fistule lacrimale qui dit tic tac   / max ernst

Max Ernst
◎ *The Little Tear Gland That Says Tic Tac*. 1920
Wallpaper borders altered with gouache,
14¹/₄×10″ (sheet)
The Museum of Modern Art, New York

The Little Tear Gland That Says Tic Tac is important as a starting point for the theme of the sun and the forest, which was to recur frequently in Ernst's paintings. Here, what would become the forest in later versions looks more like a screen made of perforated metal strips. The mechanical part, the "sun," is a cogwheel that brings to mind the old-fashioned industries bordering the Rhine, with their mine elevators, always topped by a big wheel, sticking up across the landscape.

Many of the titles that Ernst gave to his Dada pictures have a very irrational relationship to the images. In this case, however, the title is rather direct; it seems to project something within the forest that is either alive or mechanically animated.

Ernst's transformation of one kind of reality into another in this collage already foreshadows Surrealism. In fact, he gave this work to André Breton, who in 1924 was to issue the Surrealist Manifesto.

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max ernst

eislandschaften eiszapfen u. gesteinsarten
des weibl. Körpers

Max Ernst

◉ *Glacial Landscapes* (*Eislandschaften Eiszapfen
u[nd] Gesteinsarten des Weibl[ichen] Körpers*). 1920
Watercolor and collage, $10 \times 9^{1}/_{2}''$
Moderna Museet, Stockholm

Ernst has frequently exploited the interplay between
printed forms (mechanically manufactured and chosen)
and forms drawn by hand (non-mechanical and made
by the artist). He does this in at least three different
ways: 1) by using printers' signs and symbols in com-
bination with drawn lines; 2) by incorporating into
his collages printed materials, often reproductions of
mechanical elements; 3) by covering a patterned sur-
face, such as wallpaper, with paint.

Ernst's use of the pattern of the wallpaper on which
this collage is painted is so ingenious that it takes quite
a while to discover it. In some places, the mechanical
parts of the pattern have been allowed to keep their
character; elsewhere, a new mechanical but hand-drawn
form has been superimposed. The ambiguity is total.

In the *frottage* (rubbing) technique that Ernst developed
in 1925, the interplay between what the artist chose and
what he fabricated is applied to organic, non-mechani-
cal materials — wood-grain or leaves. This is in line with
the Surrealists' concentration on natural forces.

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Paul Klee
German, born Switzerland,
1879—1940

◉ *Twittering Machine*
(*Zwitscher-Maschine*). 1922
Watercolor, pen and ink, 16¹/₂ × 12″
(composition)
The Museum of Modern Art,
New York

Although done only a year or two after Picabia's machinist paintings, which are also often ironic in tone, Klee's picture reveals an entirely different concept of the machine. It displays contempt of a mild but incisive kind. Instead of man-as-machine, we have here bird-as-machine (or perhaps vice versa). Klee has taken away all the machine's glorious function and left only a disturbing noise, incarnate in crazed or unhappy birds imprisoned in the image of their mechanically produced, repetitive sound. The sickly violet atmosphere around them heightens the impression of their misery.

This is an early foreshadowing of the estrangement from mechanical things and the fear of machines that were later to predominate in the art of the Surrealists.

The core of the Surrealist program was exploration of the inner depths of man's mind, and for that, there was no need for machines — at least, for any known kind of machine. To the Surrealists, the world of technology represented an intrusion, if not an actual menace.

Here we see the beginning of an attitude of rejection of the machine that would culminate in the 'thirties in outright fear or despair, as manifested for example in Giacometti's *Captured Hand* (page 159) or Chaplin's *Modern Times* (page 157). Klee's birds twitter a frightening message that seems like a foreboding of coming events. The hand crank serves to indicate that it is man himself who by his invention and mastery of technology is destroying nature.[103]

El Lissitzky (Lazar Markovich Lissitzky)

Russian, 1890—1941

◎ *"Victory over the Sun": Figurines ("Sieg über die Sonne": Figurinen).* Designs 1920—1921; album published by Robert Leunis and Chapman, Hanover, 1923. Suite of 10 lithographs printed in color, each sheet $21 \times 17^{7}/_{8}$" The Museum of Modern Art, New York

In Moscow in 1920—1921, El Lissitzky began working on a huge plan for a completely mechanical theatre. It was the most radical attempt to introduce Constructivist ideas into staging. In the text below, originally published as the foreword to his album of ten color lithographs issued in 1923, Lissitzky explained how this

"electro-mechanical spectacle" was supposed to work. His conception reveals an excessively romantic attitude toward the machine. The engineer controls the whole set, which seemingly represents the universe; thanks to the machine, man can now take the place of God. Instead of actors *(Schauspieler)*, there are mechanically controlled figures *(Spielkörper)*.

It is significant that Lissitzky should have chosen as the first demonstration of his mechanized stage a play by Alexei Kruchenikh, which had been presented in St. Petersburg in 1913 with a famous decor by Malevich. It was not particularly well suited to the new stage, but what probably impressed Lissitzky was the idea of

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Radio Announcer

Postman

The Anxious

Up-to-date Globetrotter

Sportsmen

Troublemaker

Old Man (with His Head Two Steps Behind)

Gravediggers

man's ability to dominate the sun by his technical mastery. This view of the development of the technological age was to reach its culmination (and hopefully its terminus) with the dropping of the atom bomb.

The following is the fragment of a work developed in Moscow, 1920—21. Here, as in all my work, my goal is not to reform what has already existed but rather to bring into being another reality.

The magnificent spectacles of our cities are not noticed by anyone, for "anyone" is himself a participant. Each energy is applied solely to its own purpose. The whole remains amorphous. All energies must be organized as a unity, crystallized, and put on display. Thus there comes into being a WORK — *if you wish, call it a work of* ART.

We construct in a public square, open and accessible on every side, a scaffolding, which is the SPECTACLE MACHINERY. *This scaffolding provides the figures every possibility of movement. The individual parts of the scaffolding must therefore be capable of moving in various positions, rotating, extending, and so forth. The different levels must be able to interpenetrate quickly. Everything is of skeleton construction in order not to hide from view the figures running through. They are fashioned according to requirement and intentions. They glide, roll, float, within, around, and over the scaffolding. All parts of the scaffolding system and all the figures are activated by electro-mechanical forces and devices, controlled from a central station by one man. He is the* SHAPER OF THE SPECTACLE. *His place is at the midpoint of the scaffolding, at the switchboards that control all the energy. He directs the movement, sound, and light. He switches on the radio loudspeaker, and over the public square is heard the deafening clamor of railroad stations, the roaring of Niagara Falls, the hammering of a boiler factory. Instead of individual figures, the* SHAPER OF THE SPECTACLE *speaks into a telephone connected to an arc-lamp, or into some other apparatus, which transforms his voice in accordance with the character of the respective figures. Electrical phrases glow and die away. Beams of light, fractured by prisms and mirrors, follow the movements of the figures. In this way, the* SHAPER OF THE SPECTACLE *brings the most elementary action to the highest pitch of intensity. For the first presentation of this electro-mechanical* SPECTACLE, *I have used a modern piece, which was, however, composed for the stage. It is the Futurist opera,* Victory over the Sun, *by A. Kruchenikh, the inventor of sound-poetry and leader of the most modern Russian literature. The opera was first presented in Petersburg in 1913. The music is by Matiuschin (quarter-tonal). Malevich painted the sets (the curtain = a black square).*

The sun as the expression of the old cosmic energy is ripped out of the heavens by modern man, who creates his own source of energy through the power of his technical mastery. This idea of the opera is woven

Modern Man

together in a simultaneity of happenings. The language has no logic. Some singing parts are sound-poems.

The text of the opera obliged me to preserve something of human anatomy in my costume designs. The colors in various parts of these drawings, as in my Proun-works, are to be understood as material equivalents. That is: the parts of the costume designs done in red, yellow, or black do not indicate that those parts are to be executed in those colors, but rather that they are to be made out of corresponding materials — for example, shining copper, dull iron, and so forth.

I leave to others the further development and practical application of the ideas and forms presented here, and I myself go on to my next task.[104]

By 1924, however, Lissitzky already seems to have come to realize that over-exaltation of the machine and machine aesthetics had gone too far. While in a sanatorium at Locarno undergoing treatment for tuberculosis, he wrote for Schwitters' publication *Merz* a small manifesto called "Nasci" (Nature). Lissitzky opens with the exhortation: "*Enough* now of the everlasting MACHINE, MACHINE, MACHINE, when speaking of the art production of our time." The machine, he declares, is merely an instrument, and still a highly undeveloped one, for portraying the universe. In a key sentence, he states: "The machine has not separated us from nature. Through the machine we have discovered a new nature, which previously was not envisioned."[105]

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Liubov Popova. Russian, 1889—1924

◎ *Stage model for "The Magnificent Cuckold."* 1922
Wood and metal, 30″ high × 44½ wide × 27½″ deep
Institut für Theaterwissenschaft der Universität Köln,
Cologne

In Russia during the 1920s, the theatre became by
far the most important outlet for those who wanted
to create the new culture for the new society. Films by
Eisenstein, such as *Strike* (1924), or by Dziga-Vertov,
such as *The Man with the Camera* (1928), were soon
to play a major role; but at the outset, the possibilities
for experimentation in the theatre appeared even
greater, resulting in an impressive number of out-
standing plays and settings. Ideas based on Tatlin's
new "machine art" predominated. Constructivism in the
theatre is most widely known through the productions
of Meyerhold, which, like Tatlin's architecture and
sculpture, were closely linked to the aims of the Revo-
lution. To quote Ronald Hunt, one of the few Western
critics to have written about the art and theatre of
those years in Russia: ". . . Meyerhold repeatedly made it
clear that the theatre was a political institution: 'The
proletariat must completely fill the ditch that an out-
worn class has dug between art and life.' For Meyer-

hold and many others there existed a magical equation:
'proletarization = industrialization of art'."[106]

The highly influential position that those concerned
with the Russian theatre occupied during the years
after the Revolution has up to now been largely ne-
glected or misunderstood. We shall probably soon see
a growth of interest in their contributions, for their
efforts to formulate a new kind of expressivity directly
relevant to life have much in common with similar
attempts today, just as there are contemporary ana-
logies to the efforts of Tatlin and Lissitzky to bring
about a collaboration between art and technology.

Meyerhold's production of *The Magnificent Cuckold*
in 1922 was one of the first to incorporate Constructivist
ideas in the theatre. He ignored the script, which was
that of a sexy French farce, and turned the whole into
a Bolshevik comedy in which young people expressed
themselves through physical culture and athleticism.
The set and costumes by Liubov Popova were among
the most accomplished achievements of machinist dé-
cor. Popova designed a construction with a central
section about 25 feet high, incorporating several plat-
forms. It had moving elements like a windmill and discs
that could be spun. The speed of rotation changed ac-
cording to the actor's mood — for example, rapid spin-
ning denoted rage.

Aleksandr Vesnin
Russian, 1883—1959

◎ *Stage model for "The Man Who Was Thursday": Cafeteria.* 1923
Wood and metal, 31¹/₂" high × 30" wide × 20" deep
Institut für Theaterwissenschaft der Universität Köln, Cologne

Aleksandr Tairov opened the Kamerny (Chamber) Theatre in Moscow in 1914 as a vehicle for his progressive ideas of staging, which he later expressed in a book, *The Liberated Theatre.* Even his early Futurist productions departed from traditional realistic settings by baring the scaffolding and technical apparatus of the stage. After the Revolution, he developed in the Constructivist direction. *The Man Who Was Thursday* was a key example of his style, in which a comedy by G. K. Chesterton, set in the Middle Ages, was transformed into a picture of the new collectivist society. The setting by Aleksandr Vesnin, an architect who was a pupil of Tatlin's, was a skeletal, vertical construction made up of many levels, which fully utilized the new building materials and mechanical apparatus. Moving stairs, elevators, and flashing electric signs kept everything in continuous motion throughout. The actors, who represented various social types, moved and spoke in mechanical rhythms.

Among the other designers for Tairov's theatre were Alexandra Exter, Georgiy Yakulov, and Yuriy Annenkov. The sets that Yakulov designed for Prokofiev's ballet, *The Age of Steel,* probably in part inspired Chaplin's *Modern Times* (see page 157). Annenkov, who was

another of Tatlin's pupils, collaborated with Nikolay Evreinov in a restaging of *The Storming of the Winter Palace.* An outdoor, mass spectacle presented in Petrograd two years after the historical event, with a cast of 8,000, it was in part so realistic that a photograph of it has been reproduced as the event itself!

Alexandra Exter
Russian, 1882—1949

◎ *Construction for "Scène plastique et gymnastique,"* 1926
Gouache and pencil,
$18 \times 21^{3}/_{8}''$

◎ *Costume design for the film "Aelita."* 1924
Gouache and pencil,
$21^{1}/_{4} \times 14''$

Collection
Mr. and Mrs. Simon Lissim,
Dobbs Ferry, New York

The principal designer for Tairov's theatre was Alexandra Exter, one of the most important Constructivist stage designers of the 'twenties. She traveled extensively abroad, knew many of the leading avantgarde artists in different countries, and from 1925 on conducted a course in theatre arts in Paris. Her dynamic sets, as in the example reproduced here, abandoned the flat stage entirely to make use of verticals and diagonals that required much physical exertion on the part of the actors. Her costumes made the actors resemble machine-like sculpture rather than human beings. Those that she made for the film *Aelita,* a kind of Martian fantasy, show the influence of Cubism and particularly that of Léger's machine paintings.

Many of the machinist plays of this period were enacted by mannequins, very likely inspired to some extent by the figures in de Chirico's metaphysical paintings. One of the most widely known plays using machine-people was Karel Capek's *R.U.R.* The initials stand for "Rossum's Universal Robots"; it is in this play that Capek introduced the word "robot" (from the Czech word meaning "to work") to designate a worker-automaton. In 1923, Friedrich Kiesler created the setting for a production of *R.U.R.* in Berlin, making use of an electrically controlled stage with mechanical flats, films as backdrops, and mirror apparatus.[107]

Oskar Schlemmer
German, 1888—1943

◎ *Study for "The Triadic Ballet"*
c. 1921—1923
Gouache and photomontage,
$22^5/_8 \times 14^5/_8''$ (irregular; sheet)
The Museum of Modern Art,
New York (gift of Mr. and Mrs.
Douglas Auchincloss)

The idea of man as machine recurred frequently in the theatre of the early 'twenties. One of the most ambitious of such projects was *The Triadic Ballet* by Oskar Schlemmer, who had joined the staff of the Bauhaus in 1921 and remained the director of its theatre section until 1929. Adapted from an earlier dance originated in 1912, *The Triadic Ballet* had its first performance at the Landestheater in Stuttgart in 1922, was performed the next year at the Nationaltheater in Weimar during Bauhaus Week, and in 1926 was given at Donaueschingen with music composed by Hindemith for mechanical organ.

The three parts of the ballet have a total of twelve scenes, enacted by three dancers — two male and one female — in eighteen different costumes. It is, in fact, the costumes which have the principal roles. Hidden beneath padded cloth or stiff papier-mâché forms covered with metallic or colored paint, the dancers are reduced to motors for the costumes. They become abstract organisms enacting the laws of motion of the human figure in space. Schlemmer described the dilemma inherent in such a situation:

One of the emblems of our time is abstraction .... *A further emblem of our time is* mechanization, *the inexorable process which now lays claim to every sphere of life and art. Everything which can be mechanized is mechanized. The result: our recognition of that which can not be mechanized. And last, but not least, among the emblems of our time are the new potentials of technology and invention* . . .[108]

In a lecture given at the Bauhaus in 1927, Schlemmer indicated how these "emblems of our time" might ultimately transform the theatre. He foresaw:

. . . plays whose "plots" consist of nothing more than the pure movement of forms, color, and light . . . . a mechanical process without human involvement of any sort (except for the man at the control panel) . . .[109]

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László Moholy-Nagy
American, born Hungary,
1895—1946
⊚ *Nickel Construction.* 1921
Nickel-plated iron, welded,
14$^1/_8$" high,
including metal base
The Museum of Modern Art,
New York
(gift of Mrs. Sibyl Moholy-Nagy)

In 1920, at the age of twenty-five, László Moholy-Nagy left his native Hungary, and in January of the following year, after a brief stay in Vienna, arrived in Berlin. Born and brought up in a rural countryside, he was fascinated by modern cities, which had fired his imagination from the time he first saw illustrations of them in magazines. He was deeply impressed by the Constructivists, especially Tatlin and Lissitzky. Like the Russians, who also lacked previous experience of a highly developed society and the strength of its institutions, Moholy-Nagy believed that the old ways could be bypassed and that one could immediately begin to construct a new world. He therefore felt no need to participate with the Dadaists in destruction. With new technology and revolutionary politics, nothing was impossible, though he was careful to note that art must lead the way — the new art of Constructivism. For Moholy, as for so many others, Tatlin's tower was the ideal symbol of the new, and he adapted its spirals in several works. His *Nickel Construction* of 1921 is a naive, touching poem composed from elements of this optimism. He later described it as a "... completely perforated, completely broken through, piece of sculpture which demands on the one hand a developed technical knowledge, and on the other hand a mind that works abstractly; a freeing of material from its own weight, a passing beyond expressional ends."[110]

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László Moholy-Nagy

◎ *Kinetic Constructive System*
(*a structure with paths of motion
for sport and recreation*). 1922
Pen and brush and ink,
$29^7/_8 \times 21^1/_2''$
Institut für Theaterwissenschaft
der Universität Köln, Cologne

The year after his arrival in Ber-
lin, Moholy-Nagy collaborated
with Alfred Kemény in writing a
manifesto, which in its stress on
the importance of kinetic rhythms
had much in common which the
manifesto that Gabo had publish-
ed in Moscow in 1920. Kemény
and Moholy stated that: "The first
projects looking toward the dy-
namic-constructive system of
forces can be only experimental
demonstration devices for the
testing of the connections be-
tween man, material, power, and
space. Next comes the utilization
of the experimental results for
the creation of freely moving
(free from mechanical and tech-
nical movement) works of art."[111]

As a demonstration of such a
kinetic constructive system, Mo-
holy drew a spiral tower. People
are involved in this construction
through their own physical move-
ments, as they move about inside
it and become part of its function.
He later described it in detail:

The structure contains an outer path, mounting spirally,
intended for general recreation and therefore equipped
with a guard-rail. Instead of steps, it is in the form of a
ramp. The path ends at the top in a semi-circular plat-
form, which has access to an elevator shaft. The upper
end of the platform is jointed, while the lower end
emerges on a horizontal ring-shaped platform which
takes the public out by a downward escalator.

The horizontal ring-shaped platform glides downward
in respect to the elevator and by means of the turning
of the whole structure. The path of motion for it is the
inner spiral (intended for general recreation, and hence
equipped with a guard-rail). Parallel to the outer path

there is a further spiral, with the steepest practicable
incline, for the use of more athletic visitors. This, unlike
the outer path, has no rail.

Above the upper platform for the public there is a
horizontal surface forming three quarters of a ring,
which is the terminus of the "athletes' track," and is
connected with a slide pole parallel to the elevator
shaft. The slide pole, by means of a flexible attachment,
can be moved to any point on the upper ring-shaped
surface, and can also be swung to any point of the
ground level of the whole structure.

The figures indicate the scale, and the arrows the
directions of motion.[112]

László Moholy-Nagy
◎ *Light-Space Modulator*
1921—1930
Mobile construction:
steel, plastics, and wood,
59$\frac{1}{2}$" high,
including base
Busch-Reisinger Museum
of Germanic Culture,
Harvard University,
Cambridge

Moholy-Nagy joined the staff of the Bauhaus in 1923 and remained until 1928. He fulfilled many functions — teaching; planning, designing, and editing the Bauhaus publications; and pursuing his interest in photography.

His light-display machine or *Light-Space Modulator* is the great monument of the Bauhaus Constructivists' enthusiasm for the machine. (He gave it the name *Licht Requisit* — "Light Prop" — because he believed it could be adapted as a stage property.) Moholy-Nagy worked on it for nine years, from 1921, when he was twenty-six, until 1930. An electrically driven, mechanically complicated machine meant to function perfectly, the *Light-Space Modulator* once had a supermachine-like chrome finish. In spite of its striking sculptural presence, it was not meant as an end result in itself. As a true machine, it was productive: it produced a light play.

Light-Space Modulator *seen from the opposite side*

László Moholy-Nagy
📖 *Set for "Things To Come"*
Produced by Alexander Korda, London, 1936

After leaving the Bauhaus in 1928, Moholy-Nagy worked for a year or so in Berlin, designing stage sets for the State Opera and the theatre. He traveled for several years in Europe, lived for a while in Amsterdam, and then came to London in 1935. There he engaged in a wide variety of projects, including window displays, posters, book jackets, and so forth. Alexander Korda, who was impressed by his *Light Display*, commissioned him to create special effects for *Things To Come*, a film based on a story by H. G. Wells which told of a future society, half technologists, half robots.

The fantastic technology of the Utopian city of the future would, so Moholy dreamed, eliminate solid form. Houses were no longer obstacles to, but receptacles of, man's natural life force, light. There were no walls, but skeletons of steel, screened with glass and plastic sheets. The accent was on perforation and contour, an indication of a new reality rather than reality itself.[115]

Since about 1920, Moholy-Nagy had been working with cameraless photographs, somewhat similar to Man Ray's Rayographs. He called them photograms, "...a realization of spatial tension in black-white-gray...a writing with light, self-expressive through the contrasting relationship of deepest black and lightest white with a transitional modulation of the finest grays."[113]

These abstract spaces were made dynamic when lights were projected by the *Modulator* and reflected on surrounding walls. In 1929—1930, Moholy-Nagy made with the *Modulator* his most important film, *Light Display, Black and White and Gray*. The machine was surrounded by 128 bulbs, switched on and off by a drum contact, and turned slowly while projecting on the walls the light play of its three independent sectors. Moholy Nagy wrote of *Light Display* that it employed "...all possible means of the film technique such as superimpositions,..., prisms, mirrorings, and moving light...it tries to conquer the peculiar dimension of the film, the dimension of space-time."[114]

Though Moholy-Nagy may have built the *Modulator* only as a demonstration or an intermediate step to filmmaking, the love with which its parts were conceived was a loud paean to the mechanical world. It was constructed with highly refined craftsmanship at the time when Moholy headed the metal workshop at the Bauhaus.

Fernand Léger
French, 1881—1955

◎ *Propellers*. 1918
Oil on canvas, $31^{7}/_{8} \times 25^{3}/_{4}''$
The Museum of Modern Art, New York
(Katherine S. Dreier Bequest)

Before the World War I went with Marcel Duchamp and Brancusi to an airplane exhibition. Marcel, who was a dry type with something inscrutable about him, walked around among the motors and propellers without saying a word. Suddenly he turned to Brancusi: "Painting has come to an end. Who can do anything better than this propeller? Can you?" He was very strongly attracted to these precise objects; we were also, but not so overwhelmingly as he. I myself felt a preference for the motors, for things made out of metal, rather than the wooden blades . . . . But I still remember the bearing of those great propellers. Good God, what a miracle![116]

I have used the machine as others have used the nude or the still life . . . . I was never interested in copying the machine. I invented images of machines . . .[117]

Fernand Léger
▶ *Frames from "Ballet Mécanique"*
1924
Photographed by Dudley Murphy

"The film belongs to the machine age; the theatre belongs to the age of the horse."[118] Léger's *Ballet Mécanique* was made in the same year as René Clair's *Entr'acte* (see page 96), with music by George Antheil, who declared it to be "the first piece of music that has been conceived OUT OF and FOR machines . . . the first piece IN THE WORLD conceived in one piece without interruption, like a solid shaft of steel."[119] The visual effects also were made to conform to machinelike precision: "From one end to the other the film is subjected to an arithmetical constraint, as precise as possible (number, speed, time). An object is projected to the rhythm of

6 images a second for 30 seconds.
3 images a second for 20 seconds.
10 images a second for 15 seconds."

Léger's film, however, was not so much a glorification of the machine as a demonstration of the new ways of seeing opened up by the moving-picture camera:

The technique emphasized is to isolate the object or the fragment of an object and to present it on the screen in close-ups of the largest possible scale. . . . I maintain that before the invention of the moving-picture no one knew the possibilities latent in a foot — a hand — a hat.[120]

Leger declared that in the "new realism," parts of the human body were interesting only as fragments and were of no more importance than any other things. His real admiration, in fact, was for the beauty of manufactured objects, as is clear from this sequence in *Ballet Mécanique* that he described:

Take an aluminum saucepan. Let shafts of light play upon it from all angles — penetrating and transforming it. Present it on the screen in a close-up . . . The public need never even know that this fairy-like effect of light in many forms, that so delights it, is nothing but an aluminum saucepan.[121]

Fernand Léger
◎ *The Mechanic.* 1920
Oil on canvas, 45⅝×35″
The National Gallery of Canada,
Ottawa

The spirit behind Léger's paintings with machine subjects is quite different from the ideas of the Futurists in their paintings of automobiles and trains. The Futurists' position was a kind of literary romanticism; they saw the machine as a symbol of the new, an escape from the corrupt and the antiquated.

Léger's approach was more concerned with plastic form. To him, the machine represented visual clarity and cleanliness. He found in mechanical forms a new pictorial order, an abstraction akin to architecture and geometry but which had nothing to do with nature and the way nature had been imitated by generations of painters ever since the Renaissance. "The beautiful machine is the modern beautiful subject .... Out of a thousand paintings, are two beautiful? Out of a hundred manufactured objects, thirty are beautiful and also resolve that difficulty of Art by being beautiful and useful at the same time," he wrote in 1924.[122]

This, of course, is just another form of romanticism, a reaction against traditional art and the excesses of Art Nouveau. It involved not only placing machine-made objects in a higher category than works of painting and sculpture but also exalting the "world of artisan creators" in contrast to the decadent "professional artists." Léger gave a particularly high rank in the hierarchy to "the electrician in blue smock, emperor-king, chief of us and of all."[123] This new variant of the "noble savage" theme had its historical parallel in the admiration, current at the time, for the supposed virtues of the masses.

As often happens, though Léger's reasoning may have been defective, it could nevertheless produce, as an act of faith, very interesting works of art.

Ettore Bugatti. Italian, 1881—1947

🚗 *Bugatti Type 41 — "La Royale."* 1931
20′ long, wheel base 14′2″
Henry Ford Museum, Dearborn, Michigan
Gift of Charles A. Chayne

The Bugatti Royale is without doubt the culmination of the heroic period of the automobile, when optimism and confidence in this machine were still unclouded. In the Royale, the car as the supreme effort of mechanics and the symbol of individualism and a dominating ego found its supreme expression. No effort was spared to make it the most perfect automobile ever built. Its parts

Royale town-car at Bugatti's estate in Molsheim beside sculpture by his brother, Rembrandt Bugatti

were fitted with zero tolerances, and Bugatti proudly gave each owner an unlimited lifetime guarantee.

Ettore Bugatti was born in Italy in 1881 and began as a painter. His father was an artist, designer, and architect; his brother Rembrandt was a sculptor. When he was about eighteen, Ettore contemplated a work by his brother, a specialist in animal sculpture. Thinking that he could never produce anything of equal perfection in any existing art medium, he made an immediate decision — to give up painting and combine his creative impulses with his interest in mechanics. In this still-unexploited field, he created a new kind of art work, the automobile. By the time he died, he had built over nine thousand cars.

In 1910 he moved to Molsheim in Alsace-Lorraine, where he erected his great estate-factory. He built the prototype Royale, which became his personal car, in 1927 and was so pleased with its performance that he planned to turn out 25 more. Actually, only seven were made, of somewhat reduced dimensions and engine power — probably because Bugatti himself wished to own a uniquely powerful machine. This prototype car was wrecked in an accident five years after it was built.

The Bugatti Royale was already an anachronism when it was put on the market. Ostentatious size had ceased to be fashionable, and the Depression came shortly afterward. There were few people still willing and able to buy a car that cost upwards of $40,000; and those who became rich enough could possess airplanes. Today, many of them do not even own cars, but rent them.

Dymaxion Car No. 3, 1934, photographed outside Chicago World's Fair

R. Buckminster Fuller
American, born 1895

Dymaxion Car. 1933
19′ long

Surprisingly little has been done to reconsider the structure and form that the passenger car took around 1910. The "classic" period of automobile designing in the 'twenties was concerned less with changes in function than with styling. The continued production of the traditional car is a triumph of conventions that have developed around a once new and successful idea.

The most original reconsideration of automobile construction has been done by Buckminster Fuller. Probably only a genius who was both artist and engineer would have undertaken such a task. Fuller's airflow Dymaxion car was the outgrowth of concepts that he worked out while trying to solve the problem of providing optimum shelter at minimum cost. The word "Dymaxion" (a fusion of syllables from "dynamism," "maximum," and "ions"), first coined for his model houses, was later applied to all Fuller's enterprises.

On his thirty-eighth birthday, July 12, 1933, Fuller demonstrated to the public his first Dymaxion car. Among its revolutionary features, it introduced into the automotive field streamlining similar to that used in airplane fuselages, with most of the running gear enclosed. The car had only three wheels, two in front and one behind, which gave it exceptional maneuverability.

While being driven to the Chicago airport to demonstrate its performance to an aviation expert sent on behalf of a group of English automobile enthusiasts who had ordered a second Dymaxion, the car was rammed by an automobile owned by a prominent Chicago politician. The driver of the Dymaxion was killed, and the English aviator severely injured. As the politician had managed to have his machine spirited away before re-

porters arrived, the accident was blamed on the "freak car." The inquest eventually exonerated the Dymaxion of any fault in design or structure, but the unfavorable publicity led the English buyers to cancel their order. Fuller, nevertheless, had confidence in his principles; he repaired the damaged first car, completed the second one, and used his entire family inheritance to build Dymaxion Car No. 3.

Conventional cars have forced on modern cities a complete change of urban planning and function. There have been reports of a scheme proposed in the Soviet Union to adapt cars to towns. Small, very simple electric automobiles operated by tokens and owned by the state or municipality would be offered to anyone who passed a simple test and paid an annual fee. The fee-payers would receive keys fitting all the cars. Each night, the cars would be delivered to where they would be wanted in the morning, but since most cars would be picked up where they had been left, there would be little need for this nighttime towing. Outside meters would show when batteries were running low, and they would be replaced by service stations.

Scale drawing of Dymaxion Car No. 1, 1933

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Vladimir Tatlin. Russian, 1885—1953

◎ *Letatlin.* c. 1930
Ornithopter, wood skeleton
The M. V. Frunze Museum of Aviation and Air Defense, Moscow

Tatlin's experiments in building a flying machine — called "Letatlin" from the Russian *letat,* "to fly," and his own name — represented his boldest efforts to combine art and technology. "Letatlin" was an ornithopter — a glider powered by man's own muscular energy. Gliding was very popular in the 'twenties; what was unique was not that Tatlin should embark on such a project, but that he should do so as an artist. In this work,

"the tension between constructive utilitarianism and the artistic aspect reached a maximum."[124]

The conditions of aviation (the mobility of the machines and their relationship to their environment) create gradually a greater variation of forms and construction than static technology. All this excited my attention, and caused me to make the closer acquaintance of flight. . . . An artist with experience of a variety of different materials . . . will inevitably see it as his duty to solve the technical problem with the help of new relationships in the material . . . he will try to discover a new, complicated form, which in its further development will naturally have to be technically refined in more detail. The artist shall in his work, as a counterpart to technology,

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Tatlin's drawing of "Letatlin"

present a succession of new relationships between the forms of the material. A series of forms determined by complicated curvatures will demand other plastic, material, and constructive relationships — the artist can and must master these elements, in that his creative method is qualitatively different from that of the engineer.
The further consequences are these:

1. I have selected the flying machine as an object for artistic composition, since it is the most complicated dynamic form that can become an everyday object for the Soviet masses, an ordinary item of use.
2. I have proceeded from material constructions of simple forms to more complicated: clothes, articles of utility in the environment, as far as an architectural work to the honor of the Comintern (the Monument for the Third International). The flying machine is the most complicated form in my present phase of work. It corresponds to the need of the moment for human mastery of space.
3. As a result of this work, I have drawn the conclusion that the artists' approach to technology can and will lend new life to their stagnating methods, which are often in contradiction with the functions of the epoch of reconstruction.
4. My apparatus is built on the principle of utilizing living, organic forms. The observation of these forms led me to the conclusion that the most aesthetic forms are the most economic. Art is: work with the shaping of material, in this respect. — Tatlin, 1932.[125]

When the glider projects were shown in an exhibition of Tatlin's work in 1932, they excited great controversy — not so much over the feasibility from a scientific point of view as over his ideological approach. An article by Korneliy Zelinsky, based on an interview with Tatlin, questioned his premises:

— Tell me what this is: a work of art or a technological product? ... I would very much like to know how I should understand your bird or air bicycle: as a demonstration of attractive forms or whether one really can fly with it, as with a glider ...
— I don't want people to take this thing purely as something utilitarian. I have made it as an artist. Look at the bent wings. We believe them to be aesthetically perfect.... I count on my apparatus being able

to keep a person in the air. I have taken into account the mathematical side, the resistance of the material, the surface of the wings. We have to learn to fly with it in the air, just as we learn to swim in the water, ride a bicycle and so on ... I want, also, to give back to man the feeling of flight. This we have been robbed of by the mechanical flight of the aeroplane. We cannot feel the movement of our body in the air.
— What practical importance does your apparatus have?
— The same as a glider. Has the proletariat no use for a glider? ... But, also, I really want to emphasize the aesthetic side of the thing. Now art is going out into technology.

Zelinsky took a dim view of this approach. He asked:

Can we really allow the performances of solo inventors to develop? And what about the transference of art to technology? Of course, it just won't do. A new technological creation can give an artistic impression, but it must also serve its direct technical purpose ... If "Letatlin" is a technical apparatus designed for flight, then it must fly — and if it cannot, then it is a mere toy ... The way that has led Tatlin to technology seems to us to be alien, fatiguing and wrong. From the philosophical depths out of which "Letatlin" is to fly, heavy, reactionary prejudices have congealed into a porridge: nature worship, terror of the machine, the adaptation of technology to the feelings of the individual, a naive faith in the "wisdom" of organic forms, and escape from the industrial world.... This is a form of technology that is based on artistic "vision," intuition, and not on the scientific vision of mathematics and computation ... not in haste to draw a cross over the new "Letatlin" glider, we are concerned to purify it from rotten ideological supports, blow through it with the strong winds of proletarian criticism ... This gifted artist is our camp follower, he came to work with the Revolution in the very first October days. He has acquired not a little experience: he deserves the attention and help of the Soviet public.[126]

"Letatlin" exhibited in Moscow, 1933

Photograph reproduced in *Minotaure*, No. 10, 1937, to illustrate an
article by Benjamin Péret, "La Nature dévore le progrès et le dépasse"

Arthur Rimbaud: *The Sleeper in the Valley* (1870)

It is a green hollow where a river sings
Madly catching on the grasses
Silver rags; where the sun shines from the proud
    mountain:
It is a small valley which bubbles over with rays.

A young soldier, his mouth open, his head bare,
And the nape of his neck bathing in the cool blue
    watercress,
Sleeps: he is stretched out on the grass, under clouds,
Pale on his green bed where the light rains down.

His feet in the gladiolas, he sleeps. Smiling as
A sick child would smile, he is taking a nap:
Nature, cradle him warmly: he is cold.

Odors do not make his nostrils quiver.
He sleeps in the sun, his hand on his breast,
Quieted. There are two red holes in his right side.
    Translation by Wallace Fowlie.[127]

Le Dormeur du val

C'est un trou de verdure où chante une rivière
Accrochant follement aux herbes des haillons
D'argent; où le soleil, de la montagne fière,
Luit: c'est un petit val qui mousse de rayons.

Un soldat jeune, bouche ouverte, tête nue,
Et la nuque baignant dans le frais cresson bleu,
Dort; il est étendu dans l'herbe, sous la nue,
Pâle dans son lit vert où la lumière pleut.

Les pieds dans les glaïeuls, il dort. Souriant comme
Sourirait un enfant malade, il fait une somme:
Nature, berce-le chaudement: il a froid.

Les parfums ne font pas frisonner sa narine;
Il dort dans le soleil, la main sur sa poitrine
Tranquille. Il a deux trous rouges au côté droit.

Max Ernst. French, born Germany, 1891

◎ *Garden Airplane Trap (Jardin gobe-avions)*
1935
Oil on canvas, 21¼×29″
Owned by the artist

Between 1934 and 1936, Max Ernst made a series of paintings that showed a vision of "voracious gardens in turn devoured by a vegetation which springs from the debris of trapped airplanes . . ."[128] In these pictures, ambiguous creatures hide or spy in a desert landscape, or within enclosures rather like the walls of Machu Picchu. Are they airplane-eating dragons, enormously magnified insects, or trapped machines that after falling have somehow taken on animal shapes? Ernst's mechanical forms are often equivocal, without any boundaries between animate beings and inanimate things, as there are none between humans and animals. The world represented in his Surrealist painting and sculpture is animistic, dominated by frightening spirits.

Ernst is obsessed with flight and birds. He has attributed this to an experience he had at the age of fifteen: ". . . one of his closest friends, a most intelligent and affectionate pink cockatoo, died. It was a terrible shock to Max when, in the morning, he discovered the dead body and when, at the same moment, the father announced the birth of a sister. In his imagination Max coupled these two events. . . . A dangerous confusion between birds and humans became fixed in his mind and asserted itself in his drawings and paintings."[129] With the exception of man, birds are the most common creatures in Ernst's work; in Surrealist consequence, it is logical that airplanes should be the most frequently represented machines (see page 124).

Alexander Calder. American, born 1898

◎ *"The motorized mobile that Duchamp liked."* 1932; reassembled by the artist, 1968
Wood, wire, cord, and metal, approximately 42″ high
Owned by the artist

Calder's attitude toward the mechanical world is ambiguous, yet relaxed. Born of a family of artists, he took a degree in engineering, but when drafting reawakened his interest in art he abandoned technology as a career. After several years spent studying at the Art Students League and doing free-lance illustration, he went to Paris in 1926. An innate sense for fantasy and love of motion led him to create his miniature circus, in which the animals were characterized chiefly by their movements. The circus made Calder famous throughout the Paris art world. In 1930, he paid a crucial visit to Mondrian:

I was very much moved by Mondrian's studio, large, beautiful and irregular in shape as it was, with the walls painted white and divided by black lines and rectangles of bright colour, like his paintings. It was very lovely, with a cross-light (there were windows on both sides), and I thought at the time how fine it would be if everything there moved; though Mondrian himself did not approve of this idea at all. I went home and tried to paint. But wire, or something to twist, or tear, or bend, is an easier medium for me to think in.[130]

Alexander Calder
◎ *Crank-Driven Mobile.* c. 1932
Wood, wire, and sheet metal, $23 \times 24\frac{1}{2}''$
Joseph H. Hirshhorn Collection

Calder soon began to carry out his impulse to make objects that moved. In the winter of 1931—1932, as he recalls in his autobiography: ". . . I had been working on things with a little motion, some with more motion. I had quite a number of things that went round and round, driven by a small electric motor — some with no motor — some with a crank."

One day, Marcel Duchamp came to visit Calder and saw his work:

There was one motor-driven thing, with three elements. The thing had just been painted and was not quite dry yet. Marcel said: "Do you mind?" When he put his hands on it, the object seemed to please him. . . . I asked him what sort of a name I could give these things and he at once produced "Mobile." In addition to something that moves, in French it also means motive.[131]

Duchamp helped Calder arrange a show of his work, in which "there were fifteen objects with motors and some fifteen others, all of which had moving elements. . . . The journalists did not seem to understand anything I was driving at. There were notes about '*l'art automobile,*' and a photograph of one object, likening it to a gear shift."[132]

Alexander Calder

◉ *A Universe.* 1934
Motorized mobile: iron pipe, wire, string, and wood,
40¹/₂″ high. The Museum of Modern Art, New York
(gift of Abby Aldrich Rockefeller)

. . . the underlying sense of form in my work has been the system of the Universe, or part thereof. For that is a rather large model to work from.

What I mean is that the idea of detached bodies floating in space, of different sizes and densities, perhaps of different colors and temperatures, and surrounded and interlarded with wisps of gaseous condition, and some at rest, while others move in peculiar manners, seems to me the ideal source of form. . . .

When I have used spheres and discs, I have intended that they should represent more than what they just are. . . . A ball of wood or a disc of metal is rather a dull object without this sense of something emanating from it.

When I use two circles of wire intersecting at right angles, this to me is a sphere. . . what I produce is not precisely what I have in mind — but a sort of sketch, a man-made approximation. — Calder, 1951.[133]

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Alexander Calder
(logo) *The White Frame.* 1934
Wood, wire, cord, sheet metal, and motor, 7′6″ × 9′
Moderna Museet, Stockholm

The White Frame is the largest and most ambitious of all Calder's early motorized mobiles. Its composition is based on variations on the circle: within the frame a spiral, two spheres, a ring, and a round disc are suspended and set into different kinds of motion. The emphasis on round forms may perhaps be a kind of declaration of independence from the persistent right-angledness of Mondrian's paintings.

This is the second of Calder's "motorized reliefs." It is obvious that he thought of them as paintings in which forms were put in motion through the agency of motors. The motor served to help solve an aesthetic problem, which Calder clearly posed in his non-figurative paintings but was unable to answer: Why should one position of a form within a composition be better than another?

A year or so later, Calder abandoned motors, because he felt that they produced a too regular and repetitive movement. As he explained in 1937:

I also used to drive some of my mobiles with small electric motors, and though I have abandoned this to some extent now, I still like the idea, because you can produce a positive instead of a fitful movement — though on occasions I like that too. With a mechanical drive, you can control the thing like the choreography in a ballet and superimpose various movements: a great number, even, by means of cams and other mechanical devices. To combine one or two simple movements with different periods, however, really gives the finest effect, because while simple, they are capable of infinite combinations.[134]

Although from the mid-'thirties on Calder concentrated increasingly on mobiles powered by natural forces, he has from time to time reverted to motorized mobiles.

Alexander Calder
◎ *Pantograph*. c. 1934
Motorized mobile: wood, wire, sheet metal, and motor,
45³/₄″ high
Moderna Museet, Stockholm

Calder's rejection of the motor around 1935 in favor of motion produced by natural forces — the wind or a man's hand — was part of a definite trend of those years. The highest point of repudiation of the mechanical world in this century came in the late 'thirties. Art was dominated by Picasso, who has never shown in his work the slightest interest in machines and the mechanical world. In general, interest in the rationality of constructed form was slackening at this time, while interest in the irrational and the unconscious was increasing. The element of chance, so important in the concepts of the Surrealists, could not readily be expressed through the calculated and predictable movements produced by a motor.

Although Calder's hanging mobiles of the late 'thirties seem to abandon geometry and rely on free movement and the inspiration of nature, in their basic approach they remain Constructivist. The "leaves" always float at right angles, with a vertical or horizontal orientation.

A retrospective show of early Dada works was held in Paris. . . I had added another object I had conceived in the early years: simply a metronome to the oscillating stem of which I had attached a photograph of an eye that moved with the ticking as it swung back and forth. The title was, *Object To Be Destroyed.* I really intended to destroy it one day, but before witnesses or an audience in the course of a lecture.

Be that as it may, I was in the gallery one day with my old friend Tzara who had helped organize the show, when a group of youngsters, boys and girls, filed in, some carrying portfolios, evidently coming from the Beaux Arts Academy. Suddenly, handfuls of green handbills filled the air and a voice announced to the other visitors present that this was a protest against the Dadaists and Surrealists. Then the students began taking down the works and laying them carefully on the floor so as not to damage those under glass. After which they filed out in an orderly manner.

But on the way one grabbed the metronome and disappeared with it. . . .

Afterwards I had an interesting session with the insurance expert . . . First he offered to replace the cost of the metronome, a trifle. I pointed out that one did not replace a work of art, a painting, with brushes, paints and canvas. He conceded the point: since I was a well-known artist, he would pay the full value of the insurance. Then, assuming a more intimate tone, he voiced his suspicion that I might, with this money, buy a whole stock of metronomes. That was my intention, I replied; however, I assured him of one thing — I'd change the title — instead of *Object To Be Destroyed* I'd call it *Indestructible Object.* — Man Ray, 1963.[135]

Man Ray. American, born 1890
◎ *Object To Be Destroyed.* 1932
Ink, 11¹/₂×7³/₄″. Collection Mr. and Mrs. Morton G. Neumann, Chicago

Cut out the eye from a photograph of one who is loved but is not seen any more. Attach the eye to the pendulum of a metronome and regulate the weight to suit the tempo desired. With a hammer well-aimed, try to destroy the whole with a single blow.
— Inscription on back of the drawing

Man Ray
◎ *Indestructible Object.* Original 1923;
replica of earlier *Object To Be Destroyed,* 1958
Metronome, with cutout photograph of eye on pendulum, 8³/₄″ high.
Collection Mr. and Mrs. Morton G. Neumann, Chicago

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Be Your Own Dentist! (Our Simple Home Tooth-Puller). c. 1930. Pen and ink, 6⁷/₈ (irregular) ✕ 21″

Professor Butts ("You Sap, Mail that Letter"). c. 1930. Pen and ink, 9³/₈ ✕ 19″

Rube Goldberg (Reuben Lucius Goldberg). American, born 1883

◎ Drawings for newspaper cartoons. c. 1930—1936
Owned by the artist

Rube Goldberg is a very American artist — which is not to say that he did not attract European followers; they appeared almost immediately. In April, 1921, Marcel Duchamp published in *New York Dada* a drawing by Goldberg,[136] at a time when his series of comic cartoons, syndicated in newspapers throughout the United States, had already established his reputation, and was soon to make him one of the highest paid artists in the country. Goldberg may perhaps regarded as the first pop artist — if by "pop" one means an interested acceptance of, and not too negative a way of dealing with, the popular or common manifestations of civilization.

Underlying all the complicated contraptions of Professor Lucifer Gorgonzola Butts is the idea that something man can do in a very simple, direct way can also be accomplished, through an elaborate, roundabout, and risky system, by a machine. Goldberg's drawings of Professor Butts's apparatus sabotage our confidence both in man's intelligence and in the machine's efficiency.

Goldberg's relaxed and humorous way of dealing with the intricacies of mechanization could only be born on a continent that regarded technology as the creator of a new culture, rather than the destroyer of an older one. Goldberg himself began as a student of mining engineering at the University of California, where, he has said, "big machines impressed me with their futility." His faith in technology was further undermined when the San Francisco earthquake of 1906 destroyed the city's sewage system and water mains on which he had formerly been engaged as a designer.[137]

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Professor Butts brain takes a nosedive and out comes his self-watering palm tree.

String (A) works jumping jack (B), frightening cat (C) which raises back and lifts trough (D) causing ball (E) to fall into teacup (F). Spring (G) makes ball rebound into cup (H) pulling on string (I) which releases stick (J), causing shelf (K) to collapse. Milk can (L) drops on ladle (M) and tension on string (N) tilts shoe (O) against jigger on seltzer bottle (P), squirting seltzer on ash-can spaniel who hasn't had a bath in four years — surprise causes him to turn three somersaults over apparatus (R) and water splashes naturally into bowls, running through spray (S), watering palm (T), and saving yourself a trip to Havana for tropical atmosphere.

Professor Butts' Brain Takes a Nosedive (Self-Watering Palm Tree). c. 1930. Pen and ink, $7^5/_8 \times 19^5/_8''$

As fighter is socked on chin, water from glass (A) falls on sponge (B), weight of which causes string (C) to pull trigger of pistol (D). Bullet (E) bounces off head of dumb second (F) and hits weight (G), knocking it off rest (H) — string (I) pulls tooth from mouth of resin-spaniel (J) — dog jumps up and down with pain and works handle (K) of jack (L), thereby jacking fighter off the floor — boxing rules say that a fighter is not out if his body is off the floor — if you want to argue about this go ahead — but please don't bother us.

POOR FELLOW, HE'S TAKING AN AWFUL BEATING

BOLONEY! FOR THE MONEY HE'S GETTING I'D TAKE ONE, TOO

Simple Way for a Fighter to Keep from Getting Knocked Out. c. 1930. Pen and ink, $6^3/_4 \times 21''$

Professor Butts, training for the Olympic Games, broad jumps into the Grand Canyon by mistake and, before he reaches bottom, has plenty of time to invent a neat little fire extinguisher.

Porter (A) smells smoke coming from room and in the excitement sticks his head through window screen to investigate. Little boy remembering carnival, throws baseball (B) which bounces off porter's head and breaks glass in aquarium (C), causing water to run into trough (D) and revolve paddle wheel (E) which winds rope (F), pulling knife (G) and cutting cord (H). Shoe (I) falls on baby's face, baby sheds copious tears. Splashing of tears makes bull frog (J) think of babbling brook and he starts swimming causing file (K) to cut chain (L) which breaks and allows trees (M) to snap upright and pull wet blanket (N) over burning waste basket, thereby extinguishing fire.

If the fire doesn't happen to be in the waste basket, call out the fire department.

Professor Butts Training for the Olympic Games. c. 1932, Pen and ink, $9^1/_4 \times 20^5/_8''$

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Simple Reducing Machine. c. 1936. Ink and watercolor, 14³/₈ × 22⁷/₈″

Sure Cure for Nagging Wife . . . Who Continually Criticizes Your Driving. c. 1936. Ink and watercolor, 14³/₈ × 23″

Charles Chaplin
British, born 1889
📽 *Stills from "Modern Times."* 1936
Written, directed, and produced by Charles Chaplin. Sets by Charles D. Hall. Released by United Artists

The theme of *Modern Times* is, as so often with Chaplin, the story of an individual who tries to lead his life as a member of society but is constantly rejected by society. The tramp sees the lights of the city and is drawn to them, but in the closing scene he walks away along a country road. In *Modern Times,* society is symbolized by the factory and its machines. In his foreword, Chaplin declared: *"Modern Times* is the story of industry, of individual enterprise — humanity crusading in the pursuit of happiness."[138]

The automatic feeding machine called "Beloved" that is intended to cut down lunch time is a triumph of efficiency and exploitation. The inventor who demonstrates the feeding machine behaves like a robot himself, repeating the same gestures. When the machine goes out of order, he is not at all interested in what happens to Charlie, who is fed steel nuts, has hot soup tipped down his shirt, and pie flung into his face; he is concerned only with the malfunctioning of his machine. When the monotony of endlessly tightening bolts on the conveyor belt makes Charlie go mad, he is drawn into a big machine. (Built of rubber and wood, it cost $50,000 to construct.)

Modern Times is an extremely strong manifestation of the pessimistic attitude toward technology that culminated in the late 'thirties. The point of view is not altogether negative, however. Charlie also knows how to use machines to save himself. The foreman and workers pursuing him after he has gone mad cannot catch him, for whenever he feels in danger of being trapped, he turns on the conveyor, and they have to return to their tasks.

Chaplin said of this film: "It started from an abstract idea, an impulse to say something about the way life is being standardized and channelized, and men turned into machines — and the way I felt about it."[139]

Man Ray. American, born 1890

🎞 *Untitled.* 1929
Photograph, $8^{1}/_{2} \times 7''$. The Museum of Modern Art,
New York

The Surrealists, like the Dadaists before them, frequently presented their views of the world through the device of juxtaposition — the unexpected pairing of two phenomena that logically cannot be paired. The classic and often quoted example was that given by the nineteenth-century poet Isidore Ducasse, the "comte de Lautréamont": "Beautiful as the chance encounter of a sewing machine and an umbrella on a dissecting table." Two banally normal objects, which in our way of dealing with identities have nothing to do with each other, meet where both are out of place and make love.

The atrocities of this lovemaking must have especially appealed to the Surrealists, who, unlike the Dadaists, had strong feelings of hatred toward machines. They looked upon them as opposed to nature and destroying nature, besides representing stultifying logic at the expense of spontaneity and intuition. Most Surrealist works concerned with the mechanical world show a battle between nature and machines (for example, Ernst's *Garden Airplane Trap*, page 147).

As the first to use the airbrush in painting, however, and as a photographer, Man Ray must have retained some love for machines. In this image of sadistic lovemaking, it is not altogether clear whether he is on the side of the apple or of the screw — though obviously he gives the latter a chance.

Alberto Giacometti. Swiss, 1901—1966

⊚ *The Captured Hand (Main prise).* 1932
Wood and metal, 7⁷/₈ × 23″. Kunsthaus, Zurich

"I . . . wanted to give the sensation of motion that could be induced."[140] *The Captured Hand* is Giacometti's clearest statement about the mechanical world. It is also one of his most pessimistic works — which is saying a great deal! The image of the hand about to be caught in the machine, and the idea of one's own hand turning the crank, seem to sum up the tragic predicament of our modern world. A crank is made to be turned, and before we are aware of it, without thinking of the consequences, we respond to the invitation. The evolution of technology cannot stop, though its dangers become increasingly obvious. We feel trapped in an inevitable process of escalation, which accelerates at a more and more rapid pace. The anxiety and sense of crisis that Giacometti has here rendered in terms of sculpture is the same as that manifested by Chaplin in Modern Times, or by Friedrich Georg Juenger in his strongly polemic book, *The Failure of Technology.*[141]

What Giacometti expresses with this sculpture could not have been said in a more economical, all-encompassing way. Few works of art so directly enlist the spectator's participation as does *The Captured Hand,* which in a fraction of a second converts his natural reaction to the crank into a shudder down his spine.

Hans Bellmer
German, born Poland, 1902
⦿ *Machine-Gunneress in a State of Grace*. 1937
Articulated object: wood and papier-mâché, 23⅝″ high
The Museum of Modern Art, New York

Many Surrealists of the 'thirties accepted without question the misconceptions about technology incorporated in the theories of machine-aesthetics formulated by such men as Le Corbusier, and ardently embraced by Léger. The qualities of functionalism, standardization, and utility which these theorists attributed to the machine and singled out for praise were, however, rejected in an equally uncritical, emotional way by the Surrealists.

The Surrealists were, nevertheless strongly attracted by the erotic overtones of machines and their movements. Hans Bellmer, a Berlin artist who in the early 'twenties had been associated with Grosz and Heartfield, began constructing his puppet-like figures in 1933, inspired by the doll Olympia in a Max Reinhardt production of *The*

Tales of Hoffman. Photographs of Bellmer's doll, a female mannequin that had ball joints which allowed it to be dismantled and reassembled in various erotic positions, were seen by the Paris Surrealists and reproduced in their review *Minotaure* in 1934. The *Machine-Gunneress*, done after Bellmer had visited Paris in 1936 and joined the Surrealists, recalls the often-quoted dialogue:

Masochist: "Hurt me."
Sadist: "No."
Masochist: "Thank you."

Besides reflecting the Surrealists' general skepticism toward the machine, this particularly aggressive version of Bellmer's doll alludes to the threat of the heavy war machine that was building up at the time.

Victor Brauner. Rumanian, 1903—1966

◎ *The Mechanical Fiancée.* 1945
Encaustic on paper, mounted on composition board,
$25^3/_8 \times 19^5/_8''$
Collection Julien Levy, Bridgewater, Connecticut

The use of the word "mechanical" to describe a human reaction does not imply something rational, logical, and dependent on the intellect. On the contrary, it characterizes an intuitive or "automatic" reaction. The automatism of sexual response has long been observed, from La Mettrie, who in his *L'Homme machine* (1748) allowed it a significant, though discreet, role in his mechanistic interpretation of man, down to the scientific investigations of Dr. Kinsey.

This side of human nature has colored much of our unconscious reactions to machines. The endless allusions that locomotives and the parts of a steam engine, for example, seem to make to human love-making illuminate one aspect of machine eroticism.

Matta (Sebastian Antonio Matta Echaurren)
Chilean, born 1912

◎ *The Bachelors Twenty Years After*. 1943
Oil on canvas, 38×50″. Collection Mr. and Mrs.
George Heard Hamilton, Williamstown, Massachusetts

Matta was the youngest and by far the most speculative
of the Surrealists, whom he joined in 1937. He was espe-
cially attracted by their emphasis on chance, automa-
tism, and magic relationships, and around 1942 he be-
came particularly interested in magic, cabalistic lore, and
the tarot. For obvious reasons, he was drawn to Du-
champ.[142] A year after he painted this picture, Matta
collaborated with Katherine S. Dreier on a book on the
Large Glass — one of the first manifestations of the
greatly revived interest in Duchamp's work that was to
flourish in the 'fifties and 'sixties.

In Matta's painting, the shifting planes and fragmented
treatment of space were inspired by Duchamp's machinist
works of about 1912. As in the *Large Glass,* the "bache-

lors" are confined to the lower part of the painting, but
they have become more active and involved. They have
been brought out of the age of the mechanical and old-
fashioned chemistry into the dawning era of nuclear
science and projects for the conquest of space. Here,
space has been given an undefined, apocalyptic quality.

Matta was the first artist of the postwar generation to
understand the complexity and power of cybernetics. His
attitude toward the mechanical world, however, was
basically the same as that of the traditional Surrealists; it
was one of fear and refusal. Many of his paintings of the
'forties express a sense of frustration and alienation. On
the one hand, Matta finds deeply shocking the use of the
term "the human factor" to explain an accident or a
mistake; on the other hand, he is haunted by the realiza-
tion that human destiny is often the victim of forces
beyond man's individual control — forces described by
Breton in the *Prolegomena to a Third Surrealist Mani-
festo* (1942), which Matta illustrated, as "perturbations
like the cyclone, in the face of which man is powerless
to be anything but a witness, or like war . . ."[143]

Mark Tobey. American, born 1890
◎ *The Void Devouring the Gadget Era.* 1942
Tempera on cardboard, 21⅞ × 30″. The Museum of
Modern Art, New York (gift of the artist)

Political conditions in Europe from the mid-'thirties on,
even before the outbreak of the war, made it difficult to
concentrate on anything but the problems of survival and
defense of the most elementary values. Such a climate
did not favor the birth of new ideas in art, and in the
'forties the initiative passed to the United States.

Tobey's picture, painted a year before Matta's reinter-
pretation of Duchamp's *Large Glass,* presents a new con-
ception of space, which was to be a main preoccupation
for a generation of painters. In post-Renaissance paint-
ing, space has generally been measurable by the objects
it contains. As Tobey's title indicates, a void implies a
space so vast and limitless that it tends to swallow up
everything in it. Figures and objects lose their dimen-
sions, and with them, their identity. In this painting, the
lines and figures sometimes seem familiar and recogniz-

able, yet they finally elude our interpretation. Are they
parts of machines? vessels? microbes? malevolent ani-
mals? This elusiveness of identity gives rise to a sense
of great uncertainty. Before we have time to recognize the
elements of our gadget civilization, it is shrouded in
haze. We can no longer see clearly; chaos descends.

"... if we remain fettered and restricted by human
inventions and dogmas, day by day the world of mankind
will be degraded, day by day warfare and strife will
increase and satanic forces converge toward the de-
struction of the human race."[144] 'Abdu'l-Bahá, a leader
of the Bahá'í faith to which Tobey has adhered since
1918, gave this admonition in 1912 in the course of a
visit to America.

In 1965, asked to interpret this work, Tobey replied
that its genesis was "the realization of many people and
myself that gadgets were filling up the space in which we
lived ... It could be possible that there is a warning in
this picture. Those who look carefully will in any age
decipher it, I am sure."[145] In retrospect, Tobey's painting
and its title, dating from just three years before the
dropping of the bomb, seem uncannily prophetic.

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Bruno Munari
Italian, born 1917
⊚ *Mobile.* 1952
Sheet iron and clockworks,
30³/₄″ high
Kaiser Wilhelm Museum,
Krefeld

The spring, as in a clock, is the most temperamental reservoir of mechanical energy. When wound up, it has great force; when run down, it performs most erratically. The balance wheel in a clock regulates and distributes the energy in equal parts.

Munari gave back to the spring its own unregulated behavior, and by adding two more springs in the form of thin rods that support discs, he created a wriggling dance that goes on while the force of the spring is running down; then it has to be rewound. The motor is glorified, not heroically but poetically.

Munari had his first exhibition of "useless machines" in Milan in 1935, and in 1945 began "the creation of kinetic objects, whose make-up could be varied, driven by small clockwork motors."[146] Since the early 'fifties, he has been a strong proponent of the use of technology to achieve poetic results. In 1952, the year in which he made this object, he wrote a Manifesto of Machinism that ends: "The machine must become a work of art. We shall discover the art of machines!"[147] His ideas have probably helped inspire the optimistic, anarchic machine art that was developed in the mid-'fifties by Tinguely and others.

Jean Tinguely
Swiss, born 1925
🌀 *Meta-matic*. 1953
Wire, 26³/₄″ high × 30³/₈″
wide × 11″ deep
Collection Harry Kramer,
Paris

Tinguely's form of mechanics is "meta-mechanics," which suggests an analogy with physics and metaphysics. Most of his early machines are ironic, sometimes feverish; they carelessly ignore the disciplines of the conventional machines of this world. From a machine one demands order and precision, reliability and regularity. Tinguely's point of departure is mechanical disorder. In his early works, change and movement obey only the laws of chance. He pits the emancipated machine against the functional one and gives his creations a glorious life of improvisation, happy inefficiency, and shabbiness, expressing an enviable freedom.

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Jean Tinguely
◎ *Meta-matic No. 8.* 1958
Sheet metal, wood, wire, and motor, $15\frac{1}{2}''$ high $\times 26''$ long
Moderna Museet, Stockholm

Tinguely's auto-destructive and auto-creative art machines are among the most engaging ideas of a machine society. The self-destroying machines (of which Tinguely has so far made three) shed a harsh light on our present situation and the complexity of its structure. If art is a reflection of the fundamental ideas of a civilization, one can think of few more pertinent images or symbols. These machines have the richness and beauty of all very simple and therefore very great inventions.

The "meta-matics," the art-making machines, also stretch a tentacle into the heart of our civilization. In this century, art has come to represent faith in the individual, the ultimate liberty; it typifies the fullest expression of the creative process. By contrast, the machine is used for mass production; the entire basis of its existence is standardization. We require it to be rational, efficient, and serviceable; at the same time, we are frightened of it because it has now become so clever

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Jean Tinguely
◎ *Meta-matic No. 17*
1959
Iron, 9'10" high
Moderna Museet,
Stockholm

and powerful. There is little dignity in our present relations with machines.

When one thinks in these terms about Tinguely's painting machines, it becomes evident that the basic idea is the *collaboration*. Together, man and machine produce an irrational product. Tinguely seems to hint that if we were to get on better emotional terms with machines, there could be great times. He gives us an appetite for explorations. "For me," he says, "the machine is above all an instrument that permits me to be poetic. If you respect the machine, if you enter into a game with the machine, then perhaps you can make a truly joyous machine—by joyous, I mean free. That's a marvellous thing, don't you think?"[148]

One should not overlook the fact that the meta-matics may also constitute a rather devastating critique of some of the *art informel* of the late 1950s, the date of Tinguely's invention.

Jean Tinguely

◉ *Homage to New York* (preliminary drawing). 1960
Felt pen and ink on bristol board, 22 1/8 × 28" (sheet)
The Museum of Modern Art, New York (gift of Peter Selz)

The most important of Tinguely's self-destroying machines was probably his first one, *Homage to New York*, which destroyed itself in the Sculpture Garden of The Museum of Modern Art on March 17, 1960 (see illustrations, inner covers).

*si la scie scie la scie
et si la scie qui scie la scie
est la scie que scie la scie
il y a Suissscide métallique.*

*marcel duchamp
1960*

The best description and analysis is that written shortly after the event by Billy Klüver, a Swedish-born research scientist at the Bell Telephone Laboratories in New Jersey, who was closely involved in the work.

"The Garden Party" — *8 Years Later*

I wrote *The Garden Party* two days after it happened, as a kind of personal note. Now, eight years later, on rereading it, I am struck by the many aspects of the collaboration between Jean, Harold Hodges, and myself that are still pertinent. Even though such collaboration is bound to become less naive, it seems that the same excitement is essential for it to become effective. Harold Hodges, an engineer at Bell Labs, has since made several contributions to works by Rauschenberg, Fahlström, and others.

The title of my essay comes from a review in *The Nation*.[149] — B.K.

Jean Tinguely's destructive construction No. 1 was built in the Buckminster Fuller dome at The Museum of Modern Art over a period of three weeks. When, on March 17, 1960, his machine was put into action, the spectacle was one of beautiful humor, poetry, and confusion. Jean's machine performed for half an hour and exists no more.

When Jean first told me about his idea for a self-destructive machine, he wanted a large assembly hall on Manhattan. The machine would do all kinds of wild things and finally destroy itself. A chicken-wire netting would save the audience from a similar fate. But The Museum of Modern Art came into the picture and offered Jean its Sculpture Garden as the site, and the dome to work in.

The first drawings of the machine show little resemblance to the final result. A meta-matic painting machine was there. It would create a continuously changing painting that would disappear as the paper was rolled up again into a tight roll. A text of dirty words would unfold. A Virgin Mary was to be sawed in half. Parts of the machine would tip over, others would finally collapse as dozens of saws attacked the steel construction. The noise would be terrific.

The beginning was slow. Jean bought old motors in the bizarre Canal Street shops. A weather balloon and smoke signals (that did not work) were found in a surplus store. He collected steel tubing for the structure and tools to work with. Pulleys were expensive. He wanted old bicycle wheels from junk yards. But no junk yard in the U.S. deals in such trivialities. I stumbled onto a dealer in Plainfield who was clearing out his basement and carried away 35 old rusty wheels. Jean was as excited as a child when we brought the wheels through the empty museum that evening. The dome was unheated, and the temperature was below freezing, but things began to move. "I want more wheels," he said.

The next day my wife and I raided the Summit dump. This was a gold mine. We loaded the car and parked it behind the fence on 54th Street. A child's potty and bassinet, the drum from a washing machine, and 25 more baby carriages and bicycle wheels were thrown over the fence. The Saturday-afternoon passers-by raised the inevitable question: "What's going on here?" On the other side of the fence, Jean was laughing.

The following day the first structure was almost finished. It contained a large meta-matic with the pot, the bassinet, and the drum as percussion elements. A nut beat on the pot, a clamp jumped up and down in the bassinet, and a fan motor attacked the drum. The paper would unfold from a horizontal roll at the top and be guided down on a sheet-metal trough. Here it would be painted on by an elaborate arm that Jean later worked on for two days until it was perfect. At the bottom of the structure, the continuously moving paper would be blown toward the audience by a fan. The machine was taking form.

Jean and I made another trip to the dump. This time it was the Newark city dump, which is as much a reflection of the general neighborhood as is the Summit dump. This large dump was Jean's world. He kept finding the oddest objects and formations. Spilled-out paint would make a painting to be exhibited in some fashionable gallery. Someone had left a complete bedroom suite. If he could find a willing girl (which he admitted would be difficult), this would be a place where he would like to live. "I could, you know," he said. He would spend his days in the dump as a completely free man. Out of the debris he would build large, involved constructions. Slowly he would convince the bums, living in small shacks on the dump, that what he was making was important. Eventually they would join him and help him build. Of course, art was never to be mentioned, and his constructions would never be anything else but part of the dump. It is against the background of the anarchy and chaos of the Newark city dump that I see the growth of his machine.

The bums did indeed help us, and we walked away with a cable drum, American flags, a rusty oil can, and more baby-carriage wheels, of which for some reason there were plenty. Jean kept saying constantly: "We can put anything into the machine." In the final analysis, this of course was not true. As we were going back to the museum over the Jersey flats with our load, Jean behaved like a tourist seeing the Grand Canyon for the first time. To him the landscape was extremely beautiful.

Jean was now going at a fantastic rate. But the dome was cold, and he became ill with fever. This did not stop him, however, and he called anxiously for the insides of an old piano and a radio. I was lucky. A piano dealer in the neighborhood of the museum had an old piano. "Ten dollars if you come and get it." For two dollars, Jean bought an old Addressograph machine from the museum. Now he had everything that he wanted.

On the piano he mounted about ten arms made up of old bicycle parts. These arms hit the keys of the piano like the players of a player piano. Attached to the piano was another meta-matic, a smaller one with a sponge on the painting arm. The paper came down and was again rolled into a tight roll. L'art éphémère. There were two texts that would roll by like the news bulletins on Times Square. One was vertical, and one was horizontal. "Je fais l'angle droit, tu sais," he boasted. Rising above the structure was a 25-foot-high steel tube that would support the weather balloon at the top. An old wooden radio was attached to the side of the piano and was sawed in half by a large handsaw. The whole section with the piano and the second meta-matic had dozens of wheels in it for the various operations.

The Addressograph machine was transformed into a percussion machine with cans and a big bell. It made a fantastic noise. As the big motor of the machine worked, a lever stuck under the machine would be pulled in, and the machine would fall over. This system was never tried out.

During the last days, he made two small carriages powered by their own motors. One had a giant motor and a two-foot Klaxon sitting on two baby-carriage wheels and a small pulley. This was to be placed under the piano and would at a certain moment escape, dragging odd objects behind it. The second moving contraption was a very odd thing. Jean's idea was that it would move to the side and fall into the pool of the garden. It would commit suicide. The carriage was made up of a cable drum, more wheels, and an oil can. Sticking above it was a rod to which a corner of an American flag was attached. Two nights before the set evening, we tried it out in the museum. It was a strange sight to see this wonderful creation move laboriously in the empty museum halls. As it moved, an arm tapped a march rhythm on the empty can, and the red and white piece of the flag waved back and forth furiously. Stunned spectators looked through the windows on 53rd Street at the weird and beautiful spectacle.

Destruction seemed less and less an element of the machine. The saws were replaced by joints that would break as the metal of which they were made was melted by the heat from overheated resistors. Thus the original steel tubing was sawed through, and these joints were attached to support the structure. Jean seemed happy not to have to worry about the saws, but the joints never became quite a real part of his structure. As the first meta-matic collapsed, it would fall backward. The piano, placed on a frame two feet above ground, would itself fall backward into the fallen meta-matic. The second meta-matic and the support for the balloon would be dragged along in the fall of the piano. Behind the piano, Jean mounted a carbon-dioxide fire extinguisher, concealed by wooden boards. As a lever was pulled, the extinguisher would empty itself with a big swoosh. At the same time, the bell on the Adressograph would begin to ring.

Nothing was to be touched during the operation of the machine. The various functions and elements were to be started by pre-set time-delay relays. Everything was elaborately wired mechanically and electrically. Even a flame that would burn on the piano was to be lighted electrically. All over the structure were smoke flashes and yellow smoke signals, which would be started without direct interference. This combination of electrical and mechanical control gave Jean a great freedom to develop his machine.

An involved gear system would slowly turn the piano on. After a few minutes, a bucket of gasoline would be overturned onto the flame, a burning candle, so that the piano would catch fire. Another mechanical arrangement in the first meta-matic turned three beer cans filled with paint onto the paper rolling down toward the audience. On the very top of the first structure was a trough in which gallon-sized bottles would slide down as they were pushed by a lever. When they crashed to the ground, nauseating smells would spread. A child's go-cart would be pushed back and forth in front of the structure. There must have been about a hundred different operations in the machine.

Not until the last days did Jean decide to paint his machine all white. He seemed fascinated with this color but was a little worried that the machine would look too beautiful. The only counterpoint seemed to be the balloon that would explode and hang disgustingly over the piano. The two texts were composed the night before the event on the first floor of the museum. The night-watchmen, late museum employees — everybody helped.

On the day of destruction, the temperature rose above freezing for the first time. It was slushy, and the St. Patrick's Day parade was braving the rain on Fifth Avenue. When I arrived in the morning, the museum workmen, usually accustomed to hanging delicate paintings, were struggling to get the machine out of the dome and down to the Sculpture Garden. It was slippery, and things broke. The Addressograph was damaged, and Jean became tense. At one moment I thought he was going to quit it all. But nothing could break his resources of energy, and toward the afternoon his excitement transmitted itself to everyone. The workmen were now breaking their backs to get things in order. The museum had given him carte blanche, and everything Jean wanted he got. The rain stopped.

Robert Rauschenberg, who had promised a mascot for the machine, showed up with an object called a money-thrower. When some powder in an open box was lighted, the thrust would release two springs in which he had stuck a dozen silver dollars. Rauschenberg waited for hours to have his money-thrower connected.

Earlier in the morning, I had finally got hold of various stinking liquids, which I put in the bottles. Jean had already rejected the use of nitrogen butyl mercaptan or the stink of a skunk, in spite of the fact that he had demanded the strongest stenches I could find. I had also found out how to make a thick white smoke. Since several other methods had failed us, I did not emphasize to Jean what I had found, but simply asked him if I could put it in the bassinet. He said O.K.

The Klaxon did not work. Robert Breer went for a wild last-minute chase for a 6-volt Klaxon and found one that he actually tore off an old car. No new one would do. By then he was so wet and dirty that no taxi would take him back to the museum.

The public arrived, but nobody noticed it. Jean was fixing the meta-matics, putting on the smoke flashes, and directing everybody else. Not until 6 o'clock did I get a power line to the machine. All the circuits were connected. By accident, Robert Breer turned on the fire extinguisher in the piano. The secret had been revealed, but nobody understood what had happened. I discovered that one leg on the first structure was not sawed through. It was a real irony that the last thing we did was to saw this leg off. If it had been left, the structure would presumably not have collapsed and fallen over.

At 7:30 I was finished. "On va?" "On va," said Jean. He looked as calm as if he were about to take a bus. Not once did we go over and check everything. The construction and the beginning of the destruction were indistinguishable. Bob Breer put the titanium tetrachloride in the bassinet, a friend who had helped me with the circuits put in the plug, and I set the relays. The machine was off. It was launched as it was constructed. Jean was in complete charge of his work.

The piano was to begin playing slowly as the flame on the keyboard was lighted. But the step-up transformer had broken in transport, so the motor had to be started directly at full speed. The result was that the driving sling jumped the wheel on the piano as the motor started. I went cold. No piano! Nervously, I tried to put on the sling. "Laisse-moi faire, Billy," I heard Jean's voice say calmly. A fuse had blown. It was fixed. The piano was working again, but only three notes were playing — three sad notes. Some slings were lost. I saw nothing but the machine. The audience was invisible.

After three minutes, the first meta-matic went on. But Jean had reversed the sling so the paper was rolling up instead of down. It was a bizarre effect. Earlier he had with great care put the paper in order and fixed the arm. The audience must have expected a lot from this machine. To make the situation more incredible, the motor driving the arm had not been reconnected. Thus, even if Jean had put the sling on correctly, the meta-matic would not have worked, and the empty paper would have rolled down the trough. Jean was laughing as he always did when something exciting happened. Meta-matic No. 21 produced a three-foot-long painting as the beer cans emptied on to the paper rolling in the wrong direction. And the arm he had worked on to perfection did not function. But the fan at the bottom of the structure was not without use. The smoke was coming out thick and white from the bassinet, and the fan blew it toward the audience. Ladies with mink coats who were sitting in the cafeteria could not see because of the smoke. The percussion elements were working fine.

In the sixth minute, the radio went on. Nobody could hear it because of the noise. The gasoline bucket was turned over the flame, and the piano started burning. Rauschenberg's money-thrower went off in a big

flash. The silver dollars were never seen again. The fan motor started to beat on the drum from the washing machine. But the bottles did not fall. Jean had put in too weak a string. Why? After all our haggle over the stinks! But the only thing that annoyed Jean was that the balloon did not burst. The compressed air bottle was empty. The little two-wheeled cart in front of the meta-matic started to move back and forth.

In the tenth minute, the second meta-matic started and worked beautifully. It made a black painting streak with the sponge on its arm. The horizontal text went on. Something was wrong with it. It was winding up too slowly. Jean came by: "Do you remember the little ring you picked up and asked what it was for? It was to hold the paper roll up." Meanwhile, the vertical text was finished and the end of the paper was flying over the burning piano.

Jean was walking around calmly. He stopped in front of the machine and let the photographers take pictures, posing like an actor. As he was standing there, the text "Ying is Yang" appeared on the horizontal text roll. On the photographs of him with his self-destroying machine in the background, this sentence can be read above his head.

In the eighteenth minute, the fire extinguisher in the piano was supposed to go off. It didn't. The simple reason was that the piano was now burning all the way through, and the rubber hose had burnt up and clogged the extinguisher. But the suicide carriage rolled off some ten feet. The motor was so weak that Jean had to help it along. It would never have made it to the pool anyway, and Jean knew this all along. But he never exchanged the weak motor for a stronger one, which would have been a simple operation. As a functional object, the suicide carriage was supposed to move; as a work of art, it wasn't. This was typical of Jean's relation to the motor. On other places in the machine, there were big motors that did practically nothing; and in one place, he used a motor as a counterweight! The motor was for Jean part of the sculpture.

The Addressograph machine began to work. The yellow smoke signal was lighted, and the arms banged on the empty oil cans. The bell had never been put into operation. It turned out to be a gong that strikes only once. The whole machine was somewhat sick after the bad handling in transport, and it fell over after only a few minutes.

In the twentieth minute, the resistors in the first structure were connected. After a few minutes the metal had melted, and the whole structure sagged, but it never collapsed completely and fell over. The reason was that the crossbars that held up the wheels were strong enough to keep the structure together. But the smoke flashes were lighted by the heat from the resistors.

In the twenty-third minute, the little carriage shot out from under the piano with terrific speed. Its Klaxon was working fine, and it ended up in a ladder on which the Paris-Match correspondent was standing. He turned it around, and it continued into the NBC sound equipment. Smoke and flames were coming out of its end.

The fire in the piano was rapidly spreading. At one point, Jean had tried to damp it with an extinguisher. Now the flames had eaten their way through the piano, and Jean suddenly became afraid that the extinguisher on the back of the piano might explode from the heat. He told me to get the fireman to put out the fire.

The fireman had been there all afternoon. When the fire on the piano started, I was standing next to him. He did not react, and maybe he was enjoying the spectacle. He later called up the fire department. My wife overheard him trying to explain what was going on: "You see, Joe, there is this fire . . ." It was evidently decided that the fire in the piano was not a fire. Jean called him a "théoriticien de feu."

When I realized what Jean was saying, I tried to explain the situation to the fireman. He did not understand me when I talked about an extinguisher in the piano. The first fire extinguisher from the museum arrived. The fireman was very calm, as if nothing were happening. After three minutes, the longest in my life, they finally began to put out the fire. Even then the fireman was reluctant to do so because of the electrical wiring. At this point, both Jean and I were almost desperate, but the audience apparently got the wrong impression of what was happening. They thought the fireman was the one who wanted to put out the fire, and that we were trying to prevent him. They almost lynched the poor man who brought the extinguisher. A giant misunderstanding had developed, in which only the fireman seemed to be untouched by the confusion. He told me later that, of course, fire extinguishers are not made so that they blow up from heat. There had been no danger whatsoever. The fireman liked the show, he said.

Jean Tinguely
◎ *Homage to New York,* remnant. 1960
Painted metal,
6′8¹/₄″ high × 2′5⁵/₈″ long × 7′3⁷/₈″ deep
The Museum of Modern Art, New York
(gift of the artist)

*The fire was damped and Bob Breer courageously knocked the sup-
porting pieces of wood from under the piano. Jean had not dared to
use the automatic system because of the bad effects from the transport.
The piano collapsed backward but did not fall over.*

*I separated the fire extinguisher from the piano, and the public descen-
ded on the remains for souvenirs. They walked away with the radio, the
saw, the meta-matic drawings, and lots of other things. Later the structure
was dragged down into a pile of scrap that looked incredible. The bottles
broke, so that the garden stank for two days. The junk was carried back
to the dump the next day. Only a few mementos survived. The battered
Addressograph machine was given to a photographer from the museum,
who hauled it away at great expense. It will stand and rust in his
garden. The suicide carriage was given to the museum, Bob Breer got a
funny wheel construction that had early been put out of operation by
the eager audience, and the small carriage with the big motor and the
Klaxon stands under my table. All the rest was memory and pictures.*

*In the same way as a scientific experiment can never fail, this experi-
ment in art could never fail. The machine was not a functional object
and was never treated like one. The spectacle can therefore not be
judged in terms of whether this or that thing did or did not work. During
the construction of the machine, I was constantly amazed at Jean's
disregard for the simplest rules of engineering. In one instant he would
demand that something should function, and in the next he would violate
his demand by the most trivial of actions. Jean worked as an artist. He
chose his motors and put on his slings as an artist. He was interested
only in functional operations that he could understand, so that he could
reject or accept them as he pleased. But he was also inspired by the
possibilities of engineering and realized that he could use them as long
as he was in complete control of what he was doing. As an engineer,
working with him, I was part of the machine. This new availability was
largely responsible for the size and complexity of the machine.*

*Jean's machine was conceived out of "total anarchy and freedom," as
he put it. The free and chaotic circumstances under which it was built
were a necessity and, in a way, a tremendous luxury. Jean supplied the
energy to create the freedom and was the ruler over the chaos. When
the energy was released, everything that happened was related to some
of Jean's decisions. No distinction can be made between the "random"
elements, the accidents, or the controlled parts of the spectacle. It was*

*created in its totality out of freedom and innocence. The bottles that did
not fall, the paper roll that rotated in the wrong direction, the fireman,
and the audience were all part of the same spectacle. There could exist
no paradox, no question, no "nonsense," no a priori, and no chaos in
this spectacle. It was a definite demonstration, made with love and
humor, and not a philosophical problem.*

*I do not interpret the self-destruction of Jean's machine as an act of
protest against the machine, or an expression of nihilism and despair,
as some critics have suggested. The self-destruction or self-elimination
of the machine is the ideal of good machine behavior. For anyone con-
cerned with the relations between machines and human beings, this is
an obvious truth. This idea has already been expressed by Claude
Shannon in the "Little Black Box," in which, when you pull a switch, a lid
opens and a hand emerges that throws the switch in the off position,
whereupon the lid closes again over the hand.*

*Just as in every moment we see and experience a new and changing
world, Jean's machine created and destroyed itself as a representation
of a moment in our lives. The art of the museum is related to a past time
that we cannot see and feel again. The artist has already left his canvas
behind. This art then becomes part of our inherited language, and thus
has a relation to our world different from the reality of the immediate
now. L'art éphémère, on the other hand, creates a direct connection
between the creative act of the artist and the receptive act of the
audience, between the construction and the destruction. It forces us out
of the inherited image and into contact with ever-changing reality. In one
of Jean's "manifestos," he says that we shall "be static with move-
ment." We must be the creative masters of changing reality — which we
are, by the definition of Man. The parts from which Jean's machine were
built came from the chaos of the dump and were returned to the dump.*

*Jean kept saying that he was constantly thinking about New York as
his machine took form. There are probably many connections, the most
obvious one being a machine that has rejected itself and become humor
and poetry. New York has humor and poetry, in spite of the presence
of the machine, whereas in a purely technocratic society the machine
must always be a functional object. Failures of the machine can therefore
never be allowed, because control is the necessary element of that soci-
ety. It is when the machine must function at any cost that there can be no
"Homage to New York."*

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Jean Tinguely
◉ *Madame Lacasse's Shoe*. 1960
Junk with motor, approximately 60″ high
Owned by the artist

This paroxysm of junk in motion is one of the most extreme of Tinguely's constructions from the early 'sixties. It is a ballet of poor, discarded scraps that have belonged to people's lives. The motion makes the pieces even more pathetic; they refuse to die, to lie still. The beautiful veneer of our civilization is penetrated, and the depths of destitution hidden beneath make gestures at us. It is somehow obscene. The junk seems more real than the new and shiny, partly because it is so marked by life. Even the mechanical parts are old and worn out.

The disc that dangles from the string is a ruined monochrome by Yves Klein, with whom Tinguely had collaborated in an exhibition held in Paris in 1958.[150] Obviously the disc is there to serve as a reminder of the way of all things.

At the time when Tinguely began to build machines of this kind, he was living on Walker Street in New York, close to Canal Street, the former headquarters and main outlet of the great American mechanical industry from the eighteenth century on. There were still many old shops with a glorious past dealing in machines and accessories. It would be a mistake to believe that Tinguely scorned them; it would be more correct to say that he loved them.

Jean Tinguely
◉ *Pop, Hop and Op & Co.* 1965
Painted steel, toys, feathers, etc., with motor,
3'7¼" high×6'10⅝" long
Owned by the artist

The industrialization of the New York art scene, where the journalists who write about culture expect movements in art to succeed one another like each season's fashions, is a phenomenon we have witnessed in recent years. Such mechanization of art history is all the more unnecessary, because it is totally unproductive and arises out of laziness and lack of imagination. Free expressions that have been created through individuals, reactions and inventiveness are forced into an artificial pattern of development, because it is easier to present them in that way. This mechanization is also part of the rapidly accelerated commercialization of art that has occurred in New York and elsewhere in the past few years. Art is viewed as a consumer product and sold on that basis; therefore, at the opening of every season a new model must be unveiled. Ultimately, these standards will lead to the destruction of art as the independent expression of an individual, for a society based on standardized values will not long tolerate the existence of an individualistic kind of art.

It is interesting to realize that an extensive flow of information, dissociated from any emotional involvement with art, can be as destructive as the lack of interest in it or the fear of free expression in a totalitarian state.

As a convinced individualist, Tinguely has observed this situation. The title of this work indicates his feelings about a kinetic art movement launched with the same fanfare as op art (whose title was the brainchild of *Time* magazine). "Hop" art, "mec" art, or as Hans Richter has called it, the "movement movement," would be a disaster for everyone who loves the possibilities of machines and has dedicated himself to the task of trying to understand them. As he does so often, Tinguely here uses the machine to express his opinion in an hilarious way.

Jean Tinguely
◎ *Rotozaza, No. 1.* 1967
Iron, wood, rubber balls, and motorized elements,
7′3″ high × 13′6″ long × 7′7″ deep
Owned by the artist

Tinguely has been preoccupied with the idea of the *Rotozaza* for several years; there are sketches for this first version dating from 1965. A main theme in his thinking throughout the 'sixties has been to ridicule the practical and "rational" side of the producing machine, and at the same time emphasize its beauty and flow. For many years he has been trying to find a department store that will let him fill its display windows with a series of machines that will systematically destroy the articles that it offers for sale.

The production of articles that nobody really needs, but which occupy the ground floors of all big stores, is one of the many outward symptoms of something basically wrong in a world of overproduction and undernourishment. In order to control overproduction, without going through the intricacies of selling the product, it becomes necessary for a wilfully destructive war to be going on permanently somewhere. Today, the world is spending over \$150 billion per annum on the actual or potential destruction of lives and property, as compared with the capital transfer from rich to poor countries of about \$10 billion per year — including a large share for military aid.

The *Rotozaza* is a producing machine with the process reversed. Instead of carrying away what the machine throws out, you have to throw it back in, because the machine demands it.

Because Tinguely loves machines, he hates to see them corrupted and cretinized by ruthless exploitation and greed. The cynical cycle of production for conspicuous consumption, built-in obsolescence, and expendability could hardly be better told than by the *Rotozaza* — the machine that immediately eats up its output. It is, among other things, an instead-of-war machine.

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Ed van der Elsken. Dutch, born 1926

▶ *Nigeria 1960*
Photograph, $7 \times 9^{1}/_{2}''$
Owned by the artist

Probably the greatest political problem facing the world today is the difference among various regions as regards their technological development. Many parts of Europe and America are already leaving the mechanical age to enter the electronic era, while much of Africa, for example, is only beginning to be industrialized.

To some extent, the mechanical age seems linked to the age of colonialism. Both reached their apogee in the nineteenth century; both were based on the instinct for exploitation. The world was prospected to discover and cultivate raw materials with which to feed the machines. It rarely occurred to the ruling powers that the people whose soil produced these materials, and who sweated

to bring them forth, should have any appreciable use and benefit from the products. Whenever the natives made any serious trouble, the usual response was to send a gunboat.

Up to 1950, there were four independent countries in Africa; today, there are more than forty. They are politically aware and highly nationalistic, but technologically extremely underdeveloped. Industrial output in all of Africa (except South Africa) is, in fact, less than that in Sweden alone. Unless foreign governments and private corporations unite with the African nations in a massive and long-range program of industrial development, the social and political results will probably be explosive.

Richard Stankiewicz. American, born 1922

◎ *The Apple.* 1961
Steel with motor, approximately 8′ high
Owned by the artist

About 1960, Richard Stankiewicz's "junk art" was as influential as the work of Robert Rauschenberg and Jasper Johns. This influence was perhaps felt more strongly in Europe than in America, following Stankiewicz's one-man show in Paris in October, 1960. His way of treating scrap iron introduced a completely new concept of materials into sculpture. He resurrected what had been thrown away or buried; he treated broken, rusted pieces of iron as though they were alive. There is little relation to the loving manner in which Schwitters had used discarded and downtrodden scraps in his *Merz* constructions (see page 116). Stankiewicz's approach is very direct: he awakens machine parts from their dreams and makes them come alive. Anything brought back to life in this way is frightful and menacing. Stankiewicz is apparently afraid of the power of machines; when they are smashed, their degraded strength seems even more frightening than before.

Stankiewicz's junk sculptures undoubtedly had a very strong impact on Tinguely, who saw them during his first

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visit to New York in 1960. The two artists, however, use junk in strikingly different ways. Discovery of the possibilities inherent in scrap led Tinguely to an hilarious festival of joyful sloppiness in motion, and Stankiewicz to the creation of a series of fearsome statues that emanate horror and dread.

The Apple is the only one of his works in which Stankiewicz has used motion. This is actually a kind of anti-motion machine, for the motion continually demonstrates its own futility. When one puts money into the box, the tantalizing apple swings but is never caught. The noise of the machine's vain effort is so great that the floor trembles. When more money is put in, the apple swings again, the jaws snap, and the raucous noise is repeated. The more money, the more mechanical movement, and the more loudly voiced frustration.

When *The Apple* had its first showing in the "Motion in Art" exhibition at the Moderna Museet in Stockholm in 1961, the money collected in the box was used to pay for a big party for all those who had worked on the show.

Per Olof Ultvedt. Swedish, born Finland, 1927
⊚ . . . *life.* 1962
Wood, cloth, and motors, 21⅝" high × 66½" long
Moderna Museet, Stockholm

What most interests Ultvedt in machines is their capacity to produce motion. Movement has always been important in his art. His first mobiles were created in 1955 for a ballet in Stockholm. He had his first major exhibition there in 1957 and made a film for the occasion.

Ultvedt uses motion to make hidden things become apparent and to explain something in a surprising way. The secret life of common objects in revealed to be what we might have suspected all along, had we only thought about it.

Ultvedt loves machines because they allow him to avoid the arbitrary and yet give him perfect freedom for ambiguity. Their motion requires that the forms and elements in his pieces be shaped and placed in a definite way, to be able to perform. The machine imposes an order that is functional, not aesthetic. Ultvedt likes this idea because it means that his machines step over the borders of art into the world as a whole.

His pieces clearly lead a sex life of an indolent but persistent kind. The hidden tendencies of everyday objects at once astonish us and confirm our secret suspicions.

The title of this work is, of course, part of "still life."

Robert Watts.
American, born 1923
◉ *Pony Express*
1960—1961
Wood, steel,
polyethylene, brass,
glass, motor, switches,
and light bulbs,
34″ high×15″ wide
×20″ deep
Moderna Museet,
Stockholm

About 1960, Robert Watts used different kinds of small electric motors to activate very flimsy constructions, assembled from elements of Americana — mostly new, but some from the last century. In this object, the outside of a Coca-Cola crate has been covered with pages from a Pony Express account book. The movement of the ponies is the recurring motif throughout the composition. Everything combines to create a picture of bygone America. The renunciation of craft and efficiency is an ironic denial of the American dream. The lights flashing on and off bring Coney Island nostalgically to mind.

In these works of Watts, one recognizes a spirit like that of some Abstract Expressionist painters, especially Willem de Kooning and Jackson Pollock. They have a common concern with rediscovering American sources.

Watts, who is also an art historian, specializing in primitive, pre-Columbian, American Indian, and African Negro art, began as a mechanical engineer. The pleasure that he finds in using machines for private and irrational purposes is one of the main motivations of his work.

Ray Farhner. American, born 1925

🚗 *Boot Hill Express.* 1966
Antique horse-drawn hearse with 500 h.p. Chrysler
Street-Hemi engine, 6′6″ high × 6′ wide × 12′6″ long
Owned by the artist, Raytown, Missouri

A machine that makes a comment on itself, its species, or its use becomes a highly charged object. Around the time of the First World War, the Dadaists introduced ironic self-criticism of this kind into their anti-art painting and sculpture. A similar, more recent statement is Claude Shannon's "Little Black Box." The box has a protruding handle that invites you to switch it on; when this is done, the lid opens sufficiently to allow a small hand to reach out from under it — and turn the switch off again! The object was mass produced and sold very well in novelty shops around Times Square and elsewhere. In this device, Shannon demonstrated the principle of feedback, one of the most important concepts in computer technology. Whether he was also inspired by Dada works is not known, but it seems very possible.

The *Boot Hill Express* was constructed from an antique hearse. By a reversal of time, the high-powered engine with which it is equipped is borne on its last journey by a formerly horse-drawn vehicle. Now that all mechanical machines are in a critical phase, the *Boot Hill Express* is an extremely powerful statement, commenting on the car as producer of death and disaster. The idea of built-in death has analogies with the reversal of the cycle of production and consumption that is the theme of Tinguely's *Rotozaza* (see page 174).

The hearse from which the *Boot Hill Express* was constructed was built over a century ago by the Cunningham Coach Works of New York. Besides the high-powered 1966 Chrysler Street-Hemi engine, components from many other cars, including an early Model-T Ford steering wheel, have been incorporated. The headlights and taillights are kerosene-burning lanterns from India. All metal parts are chrome plated, and the body is finished with over thirty coats of gold paint.

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Anthony Granatelli. American, born 1923

Colin Chapman. British, born 1929

🚗 *STP-Lotus Turbocar.* 1968
Turbine-engine racing car
2′8″ high × 6′3″ wide × 14′2″ long
Owned by Anthony Granatelli, STP Corporation,
Des Plaines, Illinois

The modern racing car is a very remarkable object, on the borderline between technology and art. Although it has no practical use, it is extremely functional. No one who constructs a racing car would dream of modifying his design for the sake of aesthetics, yet many of the cars must be regarded as extremely beautiful. The racing car is the apotheosis of the great dream of the 'twenties — the beauty of the functional.

Modern racing no longer has any influence on the construction of passenger cars, as it did in Levassor's day (see page 44). Nowadays, inventions made for racing are little used, even in theory, by the automobile industry to develop better and safer cars.

In 1933, Buckminster Fuller in designing his streamlined Dymaxion Car (see page 143) adapted principles of airplane fuselages. The controversial STP-Turbocars incorporate a kind of engine that has been extensively used for aircraft, as well as for speedboats and trains.

Racing is a gratuitous activity — mechanics for the sake of mechanics, speed for the sake of speed. The racer and the artist have in common that they must achieve something entirely on their own. To do so, they must commit themselves without reserve, undistracted by hobbies (though there are artists who never miss an automobile race, if they can possibly afford to go).

In terms of mechanics, there is no greater luxury than a racing car. It is an object that pushes the possible as close to the impossible as one can come.

René Magritte. Belgian, 1898—1967

⊚ *The Anger of the Gods.* 1960
Oil on canvas, 24 × 19³/₄″
Collection Joachim Jean Aberbach,
Sands Point, New York

In his painting, Magritte characteristically adapts the Surrealist device of juxtaposition. He makes use of many different kinds of short-circuit techniques — which all result in light rather than darkness. When he says, "This is a pipe" or "This is not a pipe," it is, in a sense, either an obvious truth or an obvious lie. By such self-evident statements, he succeeds in bypassing the normal and making us see a mystery.

In *The Anger of the Gods*, Magritte has short-circuited two kinds of movement, mechanical and animal motion. He pitches us into the unknown. We suddenly ask ourselves the question, "What is movement, anyway?"

The easiest way to grasp the situation of the horse and jockey is to realize what happens when you run on an escalator. This only leads to the thought that all this is taking place on a rotating ball.

Still another mystery is why the car Magritte has pictured should be so old, and why it would not seem right if it were otherwise.

Edward Kienholz. American, born 1927

Back Seat Dodge —'38 (Tableau). 1964
1938 Dodge, plaster mannequins, chicken wire,
artificial grass, Fiberglas, flock, and beer bottles,
5′6″ high × 12′ wide × 20′ long
The Kleiner Foundation, Beverly Hills, California
(courtesy of the Los Angeles County Museum of Art)

*The basic thing about Los Angeles . . . was that it
lacked the dimensions of time . . . There were no sea-
sons there, no days of the week, no night and no day;
beyond that, there was (or was supposed to be) no
youth and age. But worst and most frightening, there
was no past and future — only an eternal dizzying pres-
ent.* — Alison Lurie.[151]

In a city where death is not accepted as real, real
life, too, becomes impossible. With his tableaux, Kien-
holz has forced people to recognize time and has given
them a history, whether they want one or not.

Not only the model of the car, but also the brand
names on the beer bottles, the style of the shoes, and
the raccoon tail on the radio aerial all relate to the war
years. John Steinbeck said that a generation of Ameri-
cans was conceived in Model-T Fords. Kienholz is telling
us that during the 'forties, cars like this one produced in-
stead abortions and tears. Having become an accepted
place for lovemaking, the cars themselves had become
less innocent, and therefore less romantic.

All the qualities of Kienholz's tableaux are present in
this passion-pit car. The doors of the car can be opened;
when we look in, mirrors give back our own reflection.
We are not looking here at some specimen in a night-
mare museum devoted to the archeology of the near
past; we become participants rather than mere specta-
tors. "Kienholz involves the viewer, forces him into a con-
frontation with the present by forcing the past at him."[152]

James Rosenquist. American, born 1933

◎ *I Love You with My Ford.* 1961
Oil on canvas, 6'10³/₄ × 7'9¹/₂″
Moderna Museet, Stockholm

In Rosenquist's painting, as in Kienholz's tableau, the car, lovers, and tragedy are again associated. Disaster is here made still more explicit through the motif that at first sight creates the strongest visual impression — the bloody spaghetti (or viscera drenched in tomato sauce). The title poses the question: Can you truly love with a car without killing? There is something profoundly disquieting in the composition's strictly horizontal arrangement. The omnipresent violence that dominates the world of cars subjugates everything into deathly stillness.

Much pop art of about this time was an effort to come to terms with life in modern cities. Shortly before, the Abstract Expressionists had concentrated their interest on the extraordinary capacities of the individual; but they had left him like a king without a country, with all everyday problems excluded, and therefore unsolved.

Rosenquist deals with mass products, such as cars (which are frequent in his pictures) in an uncritical way, to the extent that he does not transform them. He depicts cars very much as they actually are, and always in their original size. By juxtaposing them with other elements, often out of scale, as here, he makes us see them more clearly and, at the same time, as mysteries. Their outer aspect is always close to reality and almost always frightening.

César (César Baldaccini)
French, born 1921
⊚ *The Yellow Buick.* 1961
Compressed automobile,
59¹/₂″ high × 30³/₄″ wide
× 24³/₄″ long
The Museum of Modern Art,
New York
(gift of Mr. and Mrs. John Rewald)

César's compressed cars play skilfully on our feelings for the automobile: the sculptural symbol of our mobility, the very machine with which most people come into intimate daily contact, and on which our present way of life in Western society is based. César shows us this relatively free and individualistic moving machine transformed into an unsculptural, completely static volume, which is still more unmovable because of its great weight. Small traces of its former individuality — its license plates and color — lie frozen on its surface like fossils embedded in stone.

The death that we here contemplate is that of the car itself. Evolution in the field of car destruction has been very rapid. The "Big Squeeze," the American hydraulic press that compresses cars into blocks, already seems to belong to our latter-day archeology. The compressed cars that César chose and used as a kind of readymade may soon perhaps be the only ones in existence. The "Big Squeeze" is no longer practical and has been superseded by a new, also very beautiful, method of destroying automobiles. Condemned cars are slowly brought up against a huge, fast-moving fan and splintered into small particles, which can then be easily sorted according to materials. The blades of the fan are of high-grade steel, but what really makes them function is the tremendous speed at which they rotate.

The evolution is a logical one. It seems far more appropriate for an object of motion to be destroyed by a confrontation with supermotion than by congealing it into its opposite, inertia.

Claes Oldenburg. American, born Sweden, 1929

⊚ *Airflow (Number 6), Soft Engine.* 1966
Stenciled and painted canvas with kapok stuffing,
53 1/8" high × 71 7/8" long × 17 3/4" deep
Collection Dr. Hubert Peeters, Bruges

"My softening is not a blurring (like the effect of atmosphere on hard forms) but *in fact* a softening, in a clear strong light. *A perception of mechanical nature as body.*"[153]

The Airflow is the most ambitious of all Oldenburg's "soft" projects. He has been working with the theme on and off since 1966 and has gone about the project of a soft car with what is, even for him, unusual care. It is easy to imagine how tempting was the idea of creating a soft version of so hard and incorruptible a machine, and how much anxiety underlay the effort. It seems significant that Oldenburg should have chosen a car from the period when they may have commanded even more attention than they do now. The Chrysler Airflow of the mid-'thirties was the first commercial streamlined automobile. It was designed by Carl Breer, father of one of Oldenburg's friends, the sculptor and film-maker Robert Breer (see page 192). On a visit to Carl Breer in Detroit in January, 1966, Oldenburg saw and studied in great detail a 1936 Airflow, one of the few still in existence.

"The Airflow is imagined as a place with many different sized objects inside it, like a gallery, a butcher shop, like The Store — and could be just as inexhaustible a subject. Science/fiction. Auto-eroticism. I am a technological liar."[154]

Among the sources of inspiration for the Airflow is a text on Walt Whitman by D. H. Lawrence, which Oldenburg inscribed on one of his numerous preparatory draw-

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Claes Oldenburg
◎ *Airflow Profile* (working drawing for sculptural print). 1968
Enlarged photographic print of pen and ink drawing, reworked, 24 × 60″
Owned by the artist

ings. Lawrence strongly attacks Whitman for his unclear, all-embracing, overwhelming, and all-consuming ways ("Whoever you are, to endless announcements —/ and of these one and all I weave the song of myself"). Lawrence identifies these qualities as American and has a strange, strong vision of Whitman as a man in a car:

*He was everything
and everything was in him. He drove an automobile with a very fierce headlight, along the track of a fixed idea through the darkness of this world. And he saw Everything that way. Just as a motorist does in the night.*

I, who happen to be asleep under the bushes in the dark, hoping a snake won't crawl into my neck; I, seeing Walt go by in his great fierce poetic machine, think to myself: What a funny world that fellow sees!

ONE DIRECTION! *toots Walt in the car, whizzing along it.*

Whereas there are myriads of ways in the dark, not to mention trackless wildernesses. As anyone will know who cares to come off the road, even the Open Road.

ONE DIRECTION! *whoops America, and sets off also in an automobile.*

ALLNESS! *shrieks Walt at a cross-road, going whizz over an unwary Red Indian.*

ONE IDENTITY! *chants democratic En Masse, pelting behind in motorcars, oblivious of the corpses under the wheels.*

God save me, I feel like creeping down a rabbit-hole, to get away from all these automobiles rushing down the ONE IDENTITY *track to the goal of* ALLNESS![155]

Claes Oldenburg
◎ *Giant Soft Fan.* 1966—1967
Vinyl, wood, and foam rubber, 10′ high × 8′5¹/₄″ wide × 7′9⁷/₈″ deep, including plug
The Museum of Modern Art, New York
(The Sidney and Harriet Janis Collection; fractional gift, 1967)

For several years, Oldenburg has been working on a series of imaginary monuments for specific sites. The *Giant Soft Fan* originated in a projected monument for Times Square — a Banana. When the banana is peeled, you get the four wings of the fan. This manner of conception is typical of the way in which Oldenburg works in gliding meanings. The metamorphosis is carried still further: situated on Bedloe's Island in New York harbor, "The Fan replaces the Statue of Liberty. This is to make you *feel* the large version of the object — i.e. *feel* the Fan the way one feels the Statue of Liberty. It's that heavy, that tall. (There is a resemblance: the base of the Statue of Liberty is somewhat like a fan base; she has this spiked ornament.)"[156]

Oldenburg's first soft fan was made in 1965. He has stated that: ". . . the interest has always concentrated for me on the cage — softening such a structure . . . Removal of the planes (which is what cage is about) results in marvelous spatial confusion, since line only thing left — has no dimensions."[157] This seems in a way to be the opposite of Gabo's "constructed heads" (see page 106).

The *Giant Soft Fan* was first exhibited suspended from the top of the Buckminster Fuller dome for the United States Pavilion at Expo '67, "which may make it a representative object."[158]

Robert Rauschenberg. American, born 1925

⊚ *Pantomime.* 1961
Combine painting: oil on canvas with electric fans, 7×5′
Leo Castelli Gallery, New York

In his "combine-paintings," Rauschenberg conscious-
ly explores the no-man's land between art and life. In
many of them, he uses technical devices to involve the
surrounding space. Some, for example, incorporate ra-
dios, whose sound fills the space of the room. The
sound belongs both to the piece and to "life." Others
contain electric lights that serve the same purpose.

The play of the two fans in *Pantomime* is one of the
subtlest uses of mechanical means in a work of art. The
two currents of air move over the painting behind them,
keeping it fresh and in constant relation to the atmo-
sphere of the room. The display of electric cords con-
nects the work of art to the current of life.

Robert Rauschenberg (artist)

Billy Klüver. Swedish, born 1927 (engineer)

◎ *Oracle.* 1965

5-part construction: sheet metal with iron, rubber tires, glass fragments, batteries, wire, electrical and electronic components, 59″ high × 57″ wide × 24″ deep;
62″ high × 57″ wide × 35″ deep;
71″ high × 46″ wide × 23³/₄″ deep;
56″ high × 40″ wide × 23″ deep;
62″ high × 91″ wide × 17″ deep
Leo Castelli Gallery, New York

Oracle is one of the first large-scale projects in which an artist and an engineer collaborated to construct a technically complex work. Its antecedent was one of Rauschenberg's combine-paintings of 1959, *Broadcast,* in which he used radios. Wishing to achieve a situation in which the relationship between object and spectator was less restricted, he conceived the idea of developing the project in three-dimensional objects. Three years of interrupted experiments with the radio system in collaboration with Billy Klüver followed. New technical possibilities that presented themselves during the evolution of the work were incorporated into it. The progression from Rauschenberg's original "combine" idea into an increasingly advanced technology seems to indicate the direction that collaboration between artists and engineers is likely to take in the future.

The underlying theme of *Oracle* is openness and contact with the city. The components of the five sculptural pieces all come from New York, as does also the sound emitted by the five different radios. The five parts are self-contained and may be rearranged at will. The work is like a concentrate of the city situation, characterized by the accidental mixture of sound, mobility, freedom, and at the same time mutual interdependence.

Edward Kienholz
⊚ *The Friendly Grey Computer —
Star Gauge Model 54.* 1965
Motorized construction:
rocking chair, doll's legs,
metal case, instrument boxes,
lights, switches, panel with numbers,
index cards, instruction sheet,
and telephone receiver,
40″ high × 39¹/₈″ wide × 24¹/₂″ deep,
on aluminum sheet 48¹/₈ × 36″
The Museum of Modern Art,
New York
(gift of Jean and Howard Lipman)

The computer has captured our imagination more than any other technological advance of our time. The latent fear manifested in early pictures of machine-people, such as those by Bracelli and Petitot (see pages 18—19) has been reborn, but now machines seem even more frightening. Articles in newspapers and magazines continually throw into our faces reports of the super-human speed of the computer's calculations, its infallible memory, its accuracy. Mechanical devices merely replace muscular power, but the new devices challenge the very capacities that man has regarded as making him supreme and unique — his ability to think, his brainpower.

A folklore has rapidly developed about the computer. It has become a wonder child, capable of answering any question, solving any problem. As he does so frequently, Kienholz here makes use of modern folklore. His mood, though still sardonic, is gentler than in the grim *Back Seat Dodge—'38* (see page 183). His directions for operating *The Friendly Grey Computer* advise us:

Flashing yellow bulb indicates positive answer. Flashing blue bulb indicates negative answer. Green jewel button doesn't light so it will not indicate anything. Computers sometimes get fatigued and have nervous breakdowns, hence the chair for it to rest in. If you know your computer well, you can tell when it's tired and sort of blue and in a funky mood. If such a condition seems imminent, turn rocker switch on for ten or twenty minutes. Your computer will love it and work all the harder for you. Remember that if you treat your computer well it will treat you well.

Kienholz kindly programmed the computer to give more "yes" than "no" answers. A question random-found on a card: "Will I ever get a boyfriend?"

Konrad Klapheck. German, born 1935

⊚*Ideal Husband (Der Mustergatte).* 1964
Oil on canvas, 59$\frac{1}{8}$×51$\frac{1}{4}$"
Collection P. Janlet, Brussels

Klapheck's personified machines are a reminder that Freud regarded all the manufactured articles that surround us as sexual symbols. They can be divided into male or female. In Klapheck's well-dusted world, the typewriter is male, because "all the most important decisions of our lives have been taken over by it. It has become a substitute for the father, the politician, the artist."[159]

"With the help of the machine, I can draw things out of myself that were previously unknown to me; it compels me to yield up my most secret wishes and innermost thoughts."[160]

The world of Klapheck's machines seems somewhat similar to the society, rooted in ceremony and established convention, that Luis Buñuel has described and revolted against in his film *L'Age d'or* (1930). In such a milieu, people are so indoctrinated that their behavior can be predicted with nearly complete certainty. They react like automata; a given stimulus will almost invariably produce a given reaction. It is a world of human machines, each fulfilling its so-called tasks, regardless of what these may lead to in terms of good or evil. Klapheck has discovered what they are up to and is observing them.

Robert Breer. American, born 1926

◎ *Rug.* 1967
Kinetic sculpture: plastic sheet and battery-driven
metal wagons, 3″ high × 36″ wide × 48″ deep
Moderna Museet, Stockholm

The functioning of hidden mechanisms has become
as interesting for artists in the 'sixties (for example,
Ultvedt, page 178; Shannon, opposite) as the display of
mechanical parts was a few years earlier. We have
come full circle to concealing mechanism, as Vaucanson
and Jacquet-Droz did in their automata (see pages 20—
21). In fact, the philosophical problem of distinguishing
what has been created by God or nature, and what has
been created by man, is identical. Breer has said of *Rug:*
"The only way I can think of it in relation to a machine is

that since it's not an animal, it must be a machine."

In *Rug,* the interaction of the rational motor and the
non-rational forms seems an accurate way of portraying
the conditions of our existence. When we want to see
the motors of our cars, we are used to raising hard
hoods. Here, the artificial yet somehow organic-looking,
soft, metal-colored, plastic material presents a contrast
to the metal motors we suspect are hidden under it. Our
reactions are ambivalent. We feel incapable of stopping
the inexorable, uncompromising movements of the rug;
its determinism repels us and inspires a vague uneas-
iness. At the same time, we could easily handle the
light material and small-sized rug. We become inclined
to protect this helpless creature. The conflict grows
acute and complete; as so often, we oscillate between
disgust and sympathetic inclination.

Thomas Shannon. American, born 1947

⊚ *Squat*. 1966
Metal, plexiglass, and electronic components with live
plant, in two parts: a) stand with plant, 25″ high
×30″ wide×21″ deep at base; b) main element,
25″ high×51″ wide×64″ deep (floor area),
arms, 77″ long (extended)
Collection John Kingsley Shannon, Chicago

To create a more intense communication between ob-
jects of art and the public is one main trend of the
'sixties. Many artists have tried to replace the rather ab-
stract cerebral and emotional relationship between
traditional painting and sculpture and the spectator with
a more physical and direct involvement. The creation
of "environments" and "intermedia" spectacles have
been efforts in this direction.

Technology offers the possibility of creating objects
that respond to the spectator's action, for example his
voice or his movements. This opens up a vast field.

Squat, which combines mechanical, electronic, vege-
table and animal elements, anticipates the time when
brains can be channeled directly to computers.

The plant and the body of the spectator/participant
each have an electric potential, which is utilized to
activate the motors. When the plant is touched, a small
electrical charge is transmitted and amplified to switch
on a vibrating circuit. Touch, motors on; touch again,
motors off. When the motors are on, the three roller
appendages retract and extend in sequence, making
the three-legged bulk undulate. Simultaneously, another
motor makes the two mirror appendages alternately ex-
tend and retract. Shannon says: "That describes what
happens except for the hums, chirps, and creaks that
continually change."

Takis (Takis Vassilakis). French, born Greece, 1925
⊚ *Tele-Sculpture.* 1960
3-part construction: electromagnet, cork and wood
with magnets, steel wire, $10^5/_8''$ high
The Museum of Modern Art, New York
(gift of Dominique and John de Menil)

The principle underlying this work is a simple one. The upright cylinder is an electromagnet that switches on and off at regular intervals. When it is on, it attracts the suspended black spool-shaped form and repels the white sphere; when it is off, the black and white forms mutually attract one another. The rather mysterious force of magnetism, in contrast to the more "rational, understandable" force displayed in mechanical apparatus, gives to Takis' sculpture an intangible discontinuity.

Takis has made many versions of this work. He has used magnets so extensively that his work has become almost synonymous with magnetic devices, and few other artists have cared to use them. It might seem one of the drawbacks of the anarchic individualism of modern art that once an artist has laid claim to an effect, others fear to use the same means lest they be called plagiarists. But a certain lack of courage and snobbishness may be rather more to blame for this.

Hans Haacke
German, born 1936
◎ *Ice Stick*. 1966
Refrigeration unit, 54″ high,
on base 14″ high
Howard Wise Gallery,
New York

For several years, Haacke has been doing works in which the central theme is collaboration with forces of nature. He has, for example, used a breeze to move a veil. He has kept his work clean and pure, and has isolated the agency employed, leaving nothing to chance.

Haacke's use of cold to erect this sculpture by condensation of moisture in the air demonstrates his proposition in a very direct way. Technology, exemplified in the refrigeration unit, artificially produces a natural phenomenon, cold; but instead of exploiting it for some practical reason, such as the preservation of food, the artist has induced it to create an image of itself.

Marian Zazeela. American, born 1940 (visual design)
La Monte Young. American, born 1935 (sound)

◎ *Title To Be Determined.* 1967—1968
Music and light sculpture: electronic circuitry, ultraviolet light, litho film, painted acetate, and plexiglass on wooden base, 18″ high × 16″ wide × 16″ deep
Private collection, Beverly Hills, California
(on loan from the artists for their lifetimes)

This collaborative work, inspired in part by the concept of the traditional music box playing a composed work, is the first in a projected series of electronic music and light sculptures.

The work generates a pair of sine waves, whose components are locked to each other to demonstrate the frequency and the amplitude ratio standard 64:63. This ratio was selected from a subset of two categories in La Monte Young's "The Two Systems of Eleven Categories," which is the first revision of "2—3 PM 12 XI 66 — 3:43 AM 28 XII 66 for John Cage," from *Vertical Hearing or Hearing in the Present Tense.* When connected to any standard monophonic or stereo hi-fi system, the instrument produces a continuous, periodic, composite sound-waveform environment. In combination with the pink and green light design, this is a performance of a section of Zazeela and Young's music and light composition, *Map of 49's Dream: The Two Systems of Eleven Sets of Galactic Intervals Ornamental Lightyears* from a longer work, *The Tortoise, His Dreams and Journeys.*

When one moves around a room in which this music and light sculpture is functioning, the vibrations of the sound waves can be felt as well as heard. At some places in the room, the sound almost disappears, because it goes over one's head; elsewhere it becomes very strong, because it passes at ear level.

Nam June Paik. Korean, born 1932

◎ *McLuhan Caged.* 1967
Video tape recorder, 27×16″
Shadow-mask color television screen, stereo tape recorder and amplifier, 35×25″

◎ ± √ *Rondo Electronique.* 1966—1968

Bonino Gallery, New York, and Howard Wise Gallery, New York

Paik's manipulation of the TV set has the subtle brutality of judo, which turns someone's own force against himself. It is a direct frontal attack on the principal modern machine for manipulating men's minds for commercial or ideological reasons. Paik's counter-terrorism is, of course, based on ridicule.

Born in Seoul, Paik graduated in aesthetics from the University of Tokyo; studied music, art history, and philosophy in Germany; and since 1958 has been doing experimental work in electronic music in Germany and the United States. In 1965, he participated in John Cage's "Variation No. 5 with Electronic Television" at Philharmonic Hall, New York.

Only someone who had been deeply involved with the possibilities of the television medium could handle it with such precision. Paik has, in fact, a great faith in TV:

Someday artists will work with capacitors, resistors & semi-conductors as they work today with brushes, violins and junk.[161]

I have treated cathode ray tube (TV screen) as a canvas, and proved that it can be a superior canvas. From now on, I will treat the cathode ray as a paper and pen.... If Joyce lived today, surely he would have written "Finnegan's Wake" on videotape, because of the vast possibility of manipulation in magnetic information storage.[162]

EXPERIMENTS IN ART AND TECHNOLOGY
ANNOUNCES A
COMPETITION FOR ENGINEERS AND ARTISTS
AND
REQUESTS SUBMISSION OF WORKS OF ART MADE IN COLLABORATION
TO BE SELECTED FOR AN EXHIBITION AT
THE MUSEUM OF MODERN ART, NEW YORK CITY

The Museum of Modern Art, New York, has asked Experiments in Art and Technology to collaborate on a section dedicated to new technology in art as an extension of a major exhibition entitled THE MACHINE, to be held in the fall of 1968 and directed by K. G. P. Hulten, Director of Moderna Museet, Stockholm. The main body of the exhibition will be an historical survey of works of art commenting on the machine and the mechanical world.

Works to be considered for inclusion in the exhibition should be submitted by June 1, 1968 to Experiments in Art and Technology.

Experiments in Art and Technology is established to develop an effective collaboration between engineer and artist. The raison d'etre of Experiments in Art and Technology is the possibility of a work which is not the preconception of either the engineer or the artist but which is the result of the exploration of the human interaction between them. To encourage this aim in the works to be considered for the exhibition, Experiments in Art and Technology announces a competition for the best contribution by an engineer to a work of art produced in collaboration with an artist. The project may be initiated by either an artist or an engineer.

Experiments in Art and Technology will grant a first-place award of $3,000 and two second-place awards of $1,000 each to the engineer for his technical contribution to the collaboration. The jury will consist of scientists and engineers from the technical community who are not necessarily familiar with contemporary art. The jury will not be informed about the names of the collaborating enigneers. The awards will be for the most inventive use of new technology as it evolves through the collaboration of artist and engineer.

Final selection of the works to be shown at the Museum of Modern Art will be made by Mr. Hulten in consultation with the Jury.

Experiments in Art and Technology will help interested engineers and artists to establish contact. Engineers or artists who find the competition and the exhibition of interest should contact Experiments in Art and Technology at 9 East 16th Street, New York, New York, 10003. The Exhibition is international.

Art and Technology

Technology now totally dominates every step of everyday life. The artist's creativity is only slowly reestablishing its prestige, after having been almost wholly eclipsed by science and technology during the nineteenth century. During that time, artists lost the tradition of an understanding of materials and their capacities. Art and science, emotion and reason, became divorced and developed independently.

To confront the men who are shaping the new technology with the sense of individual responsibility and freedom that reigns in art is an important task. What must be abolished is the determinist notion that technology develops independent of the people who work with it. Since technology is nothing but a tool, it is neutral. Those who work with it must learn from artists to take full responsibility for what they do.

The international organization Experiments in Art and Technology (E.A.T.) was founded to try to establish a better working relationship among artists, engineers, and industry. In line with that purpose, E.A.T. agreed to arrange a competition in connection with the exhibition "The Machine as Seen at the End of the Mechanical Age." In response to the announcement of this competition, reproduced on the preceding page, approximately two hundred works, using a wide variety of means, were submitted from nine countries.

The jurors were: James M. Brownlow, International Business Machines Research Laboratories; Michael D. Golder, Plastic Research and Development Center, Celanese Plastics Company; Cyril M. Harris, Professor of Electrical Engineering and Architecture, Columbia University; John W. Pan, Bell Telephone Laboratories; and William G. Rosen, Special Assistant to the Director, National Science Foundation, and Executive Secretary of the Committee on Academic Sciences and Engineering of the Federal Council for Science and Technology.

In making the awards for the most inventive use of new technology as it evolves through the collaboration of the artist and engineer, the jurors were asked to base their judgments on these criteria: First, how inventive and imaginative is the use of technology? Second, to what extent have the engineer and the artist collaborated successfully?

The prizes mentioned in the announcement were awarded to the following engineers for their technical contributions: Ralph Martel, first prize; Frank T. Turner, Niels O. Young, second prizes. In announcing their decision, the jurors issued the following statement:

In each of the winning entries a spectrum of technology was used with great impact on the art forms. Evident is the realization that neither the artist nor the engineer alone could have achieved the results. Interaction must have preceded innovation. Going beyond a demonstration of technical prowess or an intricate orchestration of art and technology, the engineer and artist together have created more than a well-executed realization of fantasy. The unexpected and extraordinary, which one experiences on viewing these pieces, result from inventiveness and imagination, stimulated not by the brute force of technical complexity but by probing into the workings of natural laws.

In advance of the jury's deliberation, the director of the exhibition had already made a preliminary selection of nine works from the competition; they are documented on the following pages. Some very interesting environmental works, including entire rooms, unfortunately had to be excluded from consideration because of their size and the limited space available. When the jurors' decision was announced, it was remarkable that their awards should have gone to three of the nine works already selected.

Jean Dupuy
French, born 1925 (artist)

Ralph Martel
American, born 1935 (engineer)

☀ *Heart Beats Dust*. 1968
Dust, plywood, glass, light,
electronic equipment,
7′ high × 2′ wide × 2′ deep
(including active cube,
2′ on each side, *illustrated*)

The essential material of this sculpture is dust, enclosed in a glass-faced cube and made visible by a light beam of high intensity. The dust is activated by acoustic vibrations produced by the rhythm of heart beats. As an artist, Dupuy worked with polyethylene plastic, which by generating static electricity attracts and retains dust. While seeking a means to avoid this, he had the idea of utilizing the dust itself as a medium.

Like many works of recent years, *Heart Beats Dust* manifests a new form of cooperation with nature. A sensitive collaboration between natural forces within and outside the human body has here been achieved.

An earlier use of dust as an artistic medium was by Marcel Duchamp. While he was working on the *Large Glass* (see pages 80—81), after having left it untouched for a long time he found it covered with dust and decided to let some of it be the material for the sieves above the chocolate grinder. He fixed the dust in that area with varnish. In 1920, Man Ray took a famous photograph of this *Breeding of Dust (Elevage de Poussière)*.[163]

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Wen-Ying Tsai. American, born China, 1928 (artist and engineer)

Frank T. Turner. American, born 1911 (engineer)

⊛ *Cybernetic Sculpture.* 1968
Multiple stainless steel units, each 9′4″ high × 20″
diameter at base; oscillator, stroboscopic lights,
electronic equipment

This sculpture is based on the principle of the harmonic motion in a "standing wave" produced by a vibrating rod — the same idea that Gabo explored earlier (see page 106). Here, several units are grouped together. Their visual effect when in motion is continually modulated by high-frequency stroboscopic lights. The lights react to sound, such as that of a voice or the clapping of hands. The sense of contact with the sculpture that the viewer obtains is due to the subtlety of the work's reaction; the response of the trembling rods seems a direct translation of his voice.

The technical solution that produces this illusionistic feat is at once so discreet and so efficient that it strikes us as perfect.

Lucy Jackson Young. American, born 1930 (artist)
Niels O. Young. American, born 1930 (engineer)

Fakir in 3/4 Time. 1968
Base: aluminum, plastic, and motors, approximately
30″ high by 25″ wide × 16″ deep; fountain effect:
textile cord or tape, adjusting from 4 to 40′ above base

The creators of this mechanical fountain point out that it is the first machine to do the Indian rope trick. The basic principle by which a loop of otherwise limp cord could be coaxed into apparent rigidity and made to stand up was discovered only a couple of years ago. It is the same principle as that of the lariat, in which the motion of a loop of cord along its own length causes it to become rigid. In *Fakir in 3/4 Time,* the cord, instead of being swung at the end of a tether, is gobbled in and spewed out again by means of an electric motor and sheave, at the rate of 100 miles per hour. Because of its speed, the stream of cord resists deflection until it reaches the end of its loop, when it has to turn about and return to the machine. The head operates by means of a vacuum capstan.

Fakir in 3/4 Time has the elegance of a very simple solution. The choreography of this mechanical fountain is manually adjustable, but theoretically it could be programmed in a way similar to *Arm* (opposite).

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Hilary Harris. American, born 1929 (artist)

James Macaulay. Scottish, born 1923 (engineer)

👁 *Arm.* 1967—1968

Anodyzed aluminum, aluminum alloy, motors, electronic equipment, 55″ high (including base and 5 elements) ×21″ wide×16″ deep; maximum radius of arm, 55″

Arm is born out of a collaboration between an artist and an engineer who have been working together for many years, mostly in animated and documentary films. Film is, of course, a medium in which there is a constant, natural, and for the most part unproblematic collaboration between artists and engineers, who jointly develop an increasingly refined technique.

All of Hilary Harris' earlier work — which has included dance, still photography, sculpture, and film — has concentrated on movement as its underlying theme. In *Arm*, a highly advanced mechanical technology is used in combination with electronics to create a nonfigurative choreography. Each of the five articulated elements is capable of independent movement. The motor within each one is controlled by a master motor in the base, and this in turn reacts to instructions, programmed by the choreographer, which are read continuously by the mobile as it performs.

Lillian Schwartz. American, born 1927 (artist)

Per Biorn. Danish, born 1937 (engineer)

☼ *Proxima Centauri.* 1968
Plastic, ripple tank, slides, slide projector, motors,
electrical equipment; base, 55″ high × 30″ wide
× 30″ deep; globe, 30″ diameter

Changing patterns appear on the surface of a white translucent dome, which at times seems to become a gelatinous mass that shakes, breathes, and then returns to still images. As the spectator approaches the sculpture, the dome throws off a red glow, while slowly sinking into the base and thus inviting the viewer to come still closer to observe this phenomenon. The dome is now resting inside the base. Peering down into the rectangle, the viewer sees the spectacle of a series of abstract pictures focused on the globe — which having lured the viewer into the position that it desired, now shows him its material. When he leaves the sculpture, the red glow reappears as the dome surfaces. When it has assumed its original position, the red turns off, and the changing patterns begin again, awaiting the approach of another spectator.

Robin Parkinson. American, born 1943 (artist)
Eric Martin. American, born 1943 (engineer)
☀ *Toy-Pet Plexi-Ball.* 1968
Plexiglass, electrical equipment, motor, microphone,
synthetic fur bag; sphere, 11″ diameter

The *Toy-Pet Plexi-Ball* has three "eyes" and one "ear" that respond to light and sound. Its creators explain:

If a person, in the same room with the sphere, makes a loud noise, such as clapping his hands, the sphere begins to roll. If, after five seconds, he makes no other loud noises, the sphere will stop. If he continues making noise for the five seconds, the sphere continues to roll for a longer period in the same direction. If the sphere has stopped and the person makes a noise a second time, the sphere rolls in another direction. If he directs the sphere toward any other object, it eventually sees a reflection of its blinking and goes in either of two other directions. If he approaches the sphere and gets in front of the light source, the sphere sees him and begins to move in one of three directions. A controlled series of sounds can guide the sphere in the direction of another person or pursue him around the room.

The only override to the sphere's internal decision-making process consists of throwing a blanket over the sphere, or putting it in its special bag. The sphere then remains in a dormant state until released.

John William Anthes. American, born 1946 (artist)
Tracy S. Kinsel. American, born 1930 (engineer)
✺ *ELLI.* 1968
Helium-neon laser, mirrors, target, loudspeakers,
electronic and electrical devices, 51″ high
×26″ wide×26″ deep

In recent years, there have been many projects that utilized laser light. The interest of ELLI (Electronic Laser Light Image) is that it presents a three-dimensional light image that responds to information given to it. "The viewer can have dialogue with image (extension of Elli's soul) . . . the image has dialogue with surroundings." There are alternative methods of operation. In one, the music from a magnetic tape generates the audio signals that control the image; in the other, the observer controls the light images by depressing keys on the keyboard of an electronic organ. The images produced can be either stationary or in motion; by forming "chords," one can make them increasingly complex.

The completely dematerialized sculpture that Gabo predicted as a further step beyond his *Standing Wave* of 1920 has here been achieved.

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Leon D. Harmon
American, born 1922 (artist)
Kenneth C. Knowlton
American, born 1931 (engineer)
💡 *Studies in Perception, I.* 1968
Computer-processed photographic print, 30×60″

Computer graphics were created for utilitarian purposes. Among the uses are to study the field of view seen from the pilot's seat in an airplane, or to analyze a flat image in order to manipulate graphic data. The characteristics of the computer at the moment are strikingly shown in "computer art."

The computer can act as an intelligent being: process information, obey intricate rules, manipulate symbols, and even learn by experience. But since it is not capable of initiating concepts, it cannot be truly creative; it has no access to imagination, intuition, and emotion.

The computer is only a tool which, at the moment, still seems far removed from those polemic preoccupations which concern art. However, even now seen with all the prejudices of tradition and time, one cannot deny that the computer demonstrates a radical extension in art media and techniques. The possibilities inherent in the computer as a creative tool will do little to change those idioms of art which rely primarily on the dialogue between the artist, his ideas, and the canvas. They will, however, increase the scope of art and contribute to its diversity. — Jasia Reichardt, 1968.[164]

Richard Fraenkel. American, born 1923 (artist)
Jeffrey Raskin. American, born 1945 (engineer)
💡 *Picture-Frame.* 1968
Ink drawing on paper embossed frame, 12¼×14½″

Studies in Perception, I was produced by scanning a photograph with a machine similar to a TV camera and converting the electrical signals into numerical representations on a tape. The computer analyzed the image into levels of brightness, but instead of using randomly sprinkled dots to produce values of light and dark, the dots were organized into small patterns, visible at close view but imperceptible at a greater distance.

Picture-Frame was made by computation analysis of the relief molding of an old picture frame; the resultant tape was then run through a pen-and-ink arrangement on a computer to carry the design into the picture area. As Fred Waldhauer of E.A.T. remarked, with reference to the frame being preliminary to the picture: "This is probably what the computer would do, if it could think."

Notes

In the case of translated material, wherever a source in English is cited, it has been quoted verbatim. If no source is given, the translation is that of the editor, unless otherwise indicated.

1 *Leonardo da Vinci's Aeronautics.* London, Her Majesty's Stationery Office, 1967, p. 3.

2 Quoted in John Cohen, *Human Robots in Myth and Science.* South Brunswick and New York, A. S. Barnes and Company, 1967, p. 68.

3 *Bracceli: Bizarrie*, with an essay on Bracceli by Tristan Tzara. Paris, Alain Brieux, 1963.

4 *Le Mécanisme du Flûteur automate . . .* Paris, Jacques Guérin, 1738. Gravelot's engraving appeared as the frontispiece for this prospectus.

5 A detailed history of the duck is given in Alfred Chapuis and Edmond Droz, *Automata* (Neuchâtel, Editions du Griffon, 1958, pp. 239–247) and in a more recent monograph by André Doyon and Lucien Liaigre (*Jacques Vaucanson, Mécanicien de génie.* Paris, Presses Universitaires de France, 1966, pp. 65–108). It was sold by Vaucanson in 1743, shown in several German cities and St. Petersburg, and after its return from Russia was bought by a German in Helmstedt. There Goethe saw it in 1805 and described it in his journal. "We found Vaucanson's automata completely paralyzed," Goethe reported. "The duck had lost its feathers and, reduced to a skeleton, would still bravely eat its oats but could no longer digest them." Lost sight of for several decades, the duck was rediscovered about 1840, and a German clockmaker, Johann-Bartholomé Reichsteiner, undertook to put it back into working order. The task took three and a half years and cost him much labor and great expense. At its premiere in restored state at La Scala in Milan in 1844, the duck was again received with enthusiasm and then went on a new round of exhibitions. The records thereafter become confused because of the appearance in 1847 of a new duck made by Reichsteiner, on somewhat different principles; the last report of Vaucanson's original seems to be contained in a letter written from Marseilles in 1863.

6 Quoted in *Technology in Western Civilization*, edited by Melvin Kranzberg and Carroll W. Pursell, Jr. New York, Oxford University Press, 1967, vol. II, p. 39.

7 Quoted in Stephen F. Mason, *A History of the Sciences* (new revised edition). New York, Collier Books, 1962, p. 187.

8 In the first and second editions of Morghen's *Raccolta*, issued between 1764 and 1772, the voyagers to the moon were identified as "Cavaliere Wild Scull and M. de la Hire." In an article on "The Three Editions of Filippo Morghen's *Raccolta*" in *The Art Bulletin* (Chicago, vol. XIX, March 1937, pp. 112–118), Grant McColley has suggested that Morghen may have been influenced to alter the third edition by his friend Sir William Hamilton, a scientist and Fellow of the Royal Society, who was British envoy to the court of Naples.

9 *Uppfinningarnas Bok*, edited by O. W. Alund. Stockholm, 1872–1875. Passage quoted translated by K. G. P. Hultén.

10 Quoted in C. H. Gibbs-Smith, *The Great Exhibition of 1851.* London, His Majesty's Stationery Office, 1950, p. 26.

11 Quoted in *ibid.*, p. 7.

12 *Space, Time and Architecture* (3rd edition). Cambridge (Massachusetts), Harvard University Press, 1954, p. 250, p. 255.

13 Lawrence Gowing and Richard Hamilton, preface to exhibition catalogue, *Man Machine & Motion.* University of Durham, Newcastle upon Tyne, 1955.

14 *Mechanization Takes Command.* New York, Oxford University Press, 1948, p. 24.

15 Quoted in Georges Sadoul, *Histoire générale du cinéma. I. L'Invention du cinéma, 1832–1897.* Paris, Editions Denoël, 1946, p. 237.

16 *The Horse in Motion . . .*, preface by Leland Stanford, text by J. D. Stillman. Boston, James R. Osgood and Company, 1882, p. iv.

17 *Imago: Journal of Photography of the George Eastman House* (Rochester, New York), vol. II, April 1953.

18 Quoted in Beaumont Newhall, *The History of Photography from 1839 to the Present Day* (revised, enlarged edition). New York, The Museum of Modern Art, 1964, p. 97.

19 *Ibid.*, p. 99.

20 "Artist and Automobile," in *Man and Motor: The 20th Century Love Affair*, edited by Derek Jewell. New York, Walker and Co., 1967, p. 119.

21 *Histoire de la locomotion terrestre*, text and documentation by Baudry de Saunier, Charles Dollfus, and Edgar Geoffroy. Paris, *L'Illustration*, 1935, p. 278.

22 *Ibid.*, p. 279.

23 Letter from Feininger to Alfred H. Barr, Jr., August 1944, quoted in *Lyonel Feininger — Marsden Hartley.* New York, The Museum of Modern Art, 1944, pp. 7–8.

24 Stuart Legg, "A Note on Locomotive Names," *London Bulletin*, nos. 4–5, July 1938, p. 20, p. 25.
The first main-line passenger service was inaugurated in 1830. As this catalogue goes to press, the newspapers record the end of an era, with the last trip by the last British steam-powered train:
LIVERPOOL, August 11 (Reuters). — *Steam officially bowed out of British Railways today amid popping champagne corks, bunting, bells and hooters, clicking cameras — and more than a few heavy hearts. In the face of progress, 138 years after George Stephenson's Rocket opened the first train passenger service, Britain's last steam locomotive made a final nostalgic journey from here to Carlisle and back. Aboard the train were more than 400 steam enthusiasts who paid 15 guineas ($ 37.80) for the privilege of sharing the passing of "Puffing Billy" from the British scene. . . .*
A century and a half of manmade history has now gone to the wreckers' yards. . . . By 1967 all passenger traffic switched to diesel or electrified lines. And last month steam was dealt the final blow when it was decided it was no longer worthy even to haul freight . . . Today's 314-mile journey Liverpool to Carlisle was a last chance to indulge in nostalgia of the love affair with steam that embraced generations of young boys, and many of their fathers. . . .
— International Herald Tribune (Paris), August 12, 1968.

25 Quoted in Theodore Lux Feininger, *Lyonel Feininger: City at the Edge of the World.* New York, Frederick A. Praeger, 1965, p. 27.

26 *The Photographs of Jacques Henri Lartigue.* New York, The Museum of Modern Art, 1963, p. 2.

27 *Man Machine & Motion*, p. 11.

28 Translated by Reyner Banham, "Futurist Manifesto," *The Architectural Review* (London), vol. CXXVI, August–September 1959, pp. 77–80.

29 Quoted in Joshua C. Taylor, *Futurism.* New York, The Museum of Modern Art, 1961, pp. 46–48.

30 Quoted in *ibid.*, p. 129.

31 *Loc. cit.*

32 "Symbolisme plastique et symbolisme littéraire," *Mercure de France* (Paris), February 1, 1916; reprinted in *Archivi del Futurismo.* Rome, De Luca, 1962, I, pp. 204–210.

33 Translated from a manuscript written by de Chirico during his sojourn in Paris, 1911–1915; published in James Thrall Soby, *Giorgio de Chirico.* New York, The Museum of Modern Art, 1955, p. 252.

34 *Giorgio de Chirico*, p. 65.

35 *Epstein: An Autobiography.* New York, Dutton & Co., 1955, p. 56.

36 *Jacob Epstein, Sculptor.* Cleveland and New York, World Publishing Company, 1963, p. 98.

37 *Wyndham Lewis the Artist, from 'Blast' to Burlington House.* London, Laidlaw & Laidlaw, 1939, p. 78.

38 Introduction to exhibition catalogue, *Wyndham Lewis and Vorticism.* London, The Tate Gallery, July 6—August 19, 1956, p. 3.

39 *Blast No. 1*; reprinted in *Wyndham Lewis the Artist*, p. 128.

40 *Blast No. 2*; reprinted in *ibid.*, p. 151.

41 Quoted in John I. H. Baur, *Joseph Stella.* New York, Shorewood Publishers, Inc., 1963, p. 13.

42 *Loc. cit.*

43 "Suprematism," *The Non-Objective World, Part II* (1927), translated by Howard Dearstyne. Chicago, Paul Theobald, 1959; reprinted in *Modern Artists on Art: Ten Unabridged Essays*, edited by Robert L. Herbert. Englewood Cliffs (New Jersey), Prentice-Hall, Inc., 1964, p. 98.

44 Letter to Walter Pach, January 16, 1913, quoted in *Raymond Duchamp-Villon, 1876–1918*, introduction by George Heard Hamilton, notes by William C. Agee. New York, Walker and Company, 1967, p. 103.

45 *Ibid.*, p. 23.

46 "La Tour Eiffel" (1913), published in *Poème et Drame* (Paris), vol. VII, January–March 1914, pp. 22–29; translated by John Savacool in *Raymond Duchamp-Villon, 1876–1918*, p. 116.

47 "Le Contraste simultané," lecture given at Sao Paulo, Brazil, June 12, 1924; translated in exhibition catalogue, *Robert and Sonia Delaunay.* Ottawa. The National Gallery of Canada, 1965.

48 Letter from Feininger to Alfred H. Barr, Jr., August 1944, quoted in *Lyonel Feininger — Marsden Hartley*, p. 8.

49 "Marcel Duchamp, Anti-Artist," *View* (New York), series V, no. 1, March 1945 (Marcel Duchamp Number), p. 21, p. 23; reprinted in *The Dada Painters and Poets: An Anthology*, edited by Robert Motherwell. New York, Wittenborn, Schultz, 1951, p. 310.

50 Quoted by Katherine S. Dreier in her statement on Duchamp in *Collection of the Société Anonyme: Museum of Modern Art 1920*. New Haven (Connecticut), Yale University Art Gallery, 1950, p. 148.

51 Katharine Kuh, *The Artist's Voice*. New York, Harper and Row, 1960, p. 90.

52 Guillaume Apollinaire, *The Cubist Painters: Aesthetic Meditations* (1913), translated by Lionel Abel. (The Documents of Modern Art.) New York, Wittenborn and Company, 1944, p. 48.

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of Fortune. "If the *Twittering Machine* shows a limed twig, lures, and a death trap, these seem to express the idea that we are all ensnared by existence.... the raucous twittering makes us aware that ... the arrows of Death are marked for every bird that sings" (p. 69).

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135 *Self Portrait,* pp. 389—392. Although Man Ray has stated (questionnaire, July 18, 1966, Collection files, The Museum of Modern Art) that the original conception dates from 1923, the drawing (formerly in the collection of Tristan Tzara) is dated 1932, and *Object To Be Destroyed* was first exhibited in the *Exposition Surréaliste,* Galerie Pierre Colle, Paris, June, 1933.

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Bibliography

The literature on the history of technology and on various aspects of the interrelationship among machines, society, and the arts is vast. Many of these books and articles have been consulted in preparing this exhibition and its catalogue; references to specific sources will be found in the notes. The brief list below includes some useful basic books, most of which contain comprehensive bibliographies, and a few publications that have offered especially illuminating insights.

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A collection of essays, issued in conjunction with an exhibition at the Institute of Contemporary Arts, London, on the uses of the new technology to extend creativity.

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